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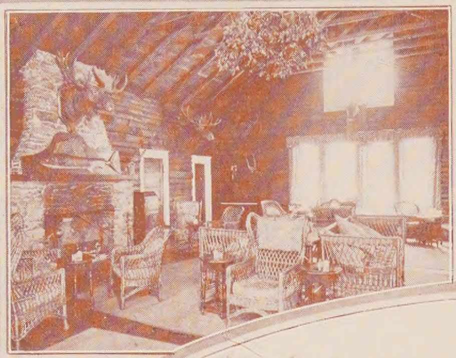

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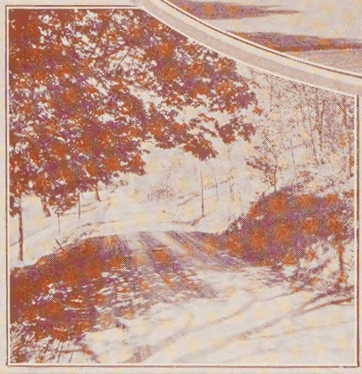

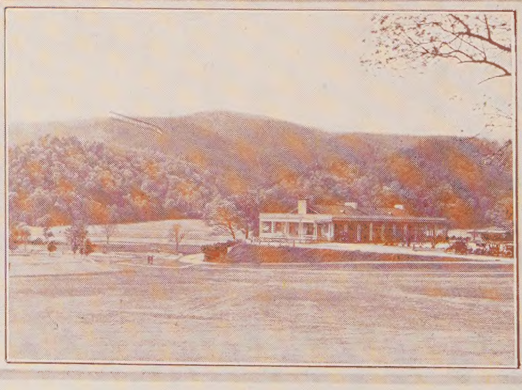

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OF THE

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American Institute of Electrical Engineers

COMING MEETINGS

Annual Convention, White Sulphur Springs, W. Va., June 21-25
Pacific Coast Convention, Salt Lake City, Utah, Sept. 7-10

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American Association of Engineers, Philadelphia, June 1-6

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National Electric Light Association

North Central Division, St. Paul, June 8-10
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Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

Vol. XLV JUNE, 1926 Number 6

Requirements for Admission and Transfer

The rapid growth of the Institute during the last few years has necessarily more directly affected the work of the Board of Examiners than that of any other group engaged in A. I. E. E. activities. Forty-two hundred applications were considered during the year ending April 30, 1926, of which one hundred and forty-four were direct admissions and two hundred and fifty-six were transfers to the grade of Member or Fellow. Each of these latter four-hundred cases were reviewed through the careful examination of the complete professional records as submitted by the applicants and the weighing of the statements of the references. Many cases are of course easily disposed of because of the unquestionable eligibility of the applicants to the grades for which the applications are made. The Examiners have found, however, that there is a considerable group, composed of doubtful cases, and it is this group that requires a large part of the Board's time. Many of these cases are doubtful apparently through the failure of the applicants to devote sufficient time and effort to the submission of their records and references.

The electrical field today is of such vast proportions that no group of men, no matter how carefully selected, is competent to judge the importance of an applicant's work where the outline of that work is confined to a simple statement of dates and positions held. Again, two or more positions with exactly the same titles but in different companies, may involve widely different responsibilities. Considering this simple illustration alone, of hundreds that continually arise, the Board of Examiners urges all applicants to furnish records in sufficient detail to give the Board a definite idea of the engineering nature of their work and the degree of responsibility imposed upon them in the execution of that work. References should be selected particularly to cover the period of work on which the application is based. This usually means the last five or ten years, depending upon the grade desired.

If those instrumental in recommending new members will impress these facts on the applicants, and those applying for transfer will keep them in mind, much unnecessary correspondence will be eliminated and action on all applications will be greatly expedited.

The Board of Examiners feel, and every member of the Institute, as well as everyone outside its membership who comes in contact with it, should feel, that admission or transfer in the A. I. E. E. is not a matter to be regarded lightly but one well worthy of every effort that can be put behind it.

Some Leaders of the A. I. E. E.

John J. Carty, pioneer in the development of the telephone art since 1879, was the twenty-eighth president of the American Institute of Electrical Engineers, through the term 1915-1916.

Mr. Carty was born in Cambridge, Mass., April 14, 1861. Starting at Boston, he has been in the Bell System continuously since he left the Cambridge Latin School in 1879. In 1887 he came to New York, and spent two years with the Western Electric Company in cable and switchboard development. In 1889, he went to the New York Telephone Company, of which he became Chief Engineer.

In 1907 he was appointed by Theodore N. Vail to the office of Chief Engineer of the American Telephone and Telegraph Company, and built up the staff through which he directed the engineering and research work of the Bell System. In 1919 he was elected vice president of the company, which position he still holds.

While at Boston, he designed and constructed the first metallic circuit multiple telephone switchboard. During 1889-1891 he published his original researches in inductive interference and upon his experiments is based the theory of transposed metallic circuits. Mr. Carty has numerous telephone inventions to his credit, including the method of the common battery now in general use, and the bridging bell which forms the basis of all farmers' party-line telephones.

Among the engineering advances made under his administration was the completion, on January 25, 1915, of the transcontinental telephone line, making possible, for the first time, the transmission of speech from coast to coast. In the same year, there was accomplished by the staff under his charge the first transmission of speech by radio across the Atlantic Ocean, across the continent to San Francisco and to the Hawaiian Islands.

From the Institute headquarters in New York, he presided over its National Meeting, held May 16, 1916 in six cities; Boston, San Francisco, Atlanta, Chicago, Philadelphia, and New York. By means of the long distance telephone, the members in these remote cities took part in the discussions and in the parliamentary proceedings of a joint meeting—the first of its kind

ever held. In a message of congratulation, President Wilson said: "To conduct such a meeting by telephone and make it possible for men scattered all over the country to listen to the proceedings and participate in them, is certainly a most interesting evidence of the inventive genius and engineering ability represented by the Institute."

In the Officers' Reserve Corps Mr. Carty was a Major and upon the declaration of war, was ordered into active service. Under the direction of the War Department, and with the cooperation of the telephone companies, he organized in the Bell System, twelve battalions of Signal Corps troops. He was promoted to Colonel in the Signal Corps, U. S. A., and served in France on the staff of the Chief Signal Officer of the A. E. F. In cooperation with that officer, he designed the telephone and telegraph system for the American Army in France, and was Signal Officer in charge of communications, American Commission to Negotiate Peace. He received the Distinguished Service Medal from General Pershing in France, the thanks of the French Army and the Cross of the Legion of Honor.

For many years, Mr. Carty has been active in the movement to encourage scientific research in universities and among the industries. He is now Vice Chairman of the Trustees for the National Research Endowment Fund for the support of pure science research, of which Hon. Herbert Hoover is Chairman. He is also a trustee of the Carnegie Institution and of the Carnegie Corporation; a member of the Council of New York University, a member of the National Academy of Sciences and the National Research Council, Honorary Member of the Franklin Institute, from which in 1903 he received the Edward Longstreth Medal for his "bridging bell system;" and the Franklin Medal in 1916, for signal eminent service in science. In 1916 the Edison Medal was bestowed upon him for "work in the science and art of telephone engineering."

The Japanese have decorated him with the Order of the Rising Sun and the Order of the Sacred Treasure, and twice their government extended to him its official thanks for services in connection with the establishment and development of the telephone system there.

He is a Brigadier General in the Reserve Corps of the United States Army, a member of the War Department Business Council, an Honorary Advisor to the Army Industrial College, and national President of the American Signal Corps Association.

Stevens Institute of Technology, and New York University have conferred upon him the honorary degree of Doctor of Engineering; Yale, Princeton, the University of Chicago, Bowdoin and Tufts the degree of Doctor of Science and from McGill University, and the University of Pennsylvania he has received the degree of Doctor of Laws.

Electrification and Farm Prosperity

The unfortunate condition of agriculture in comparison with the exceptional prosperity of other industries in this country in recent years, has called forth many suggested remedies, among which are various bills now before Congress. Prosperity, however, cannot be obtained by legistation except as it may remove obstacles, and the seasonal character of agriculture and the fact that the farmer buys his supplies at prevailing high prices and sells his product in a competitive low market are facts that cannot be legislated away.

A more promising solution of the farmer's difficulties is suggested in an address by General Guy E. Tripp, at the recent N. E. L. A. Convention. A similar solution was also given in an address by President Glenn Frank at the recent Madison Regional meeting of the A. I. E. E. The remedy is the decentralization of industry.

Electric superpower systems are vital to industrial decentralization. Without these systems, industries will not spread out into the country, regardless of advantages to be secured by doing so, but will remain in congested centers. But wherever superpower systems are well developed, power can be secured almost anywhere. Hence, as superpower systems grow, small factories will multiply in the rural districts.

Now, the chief obstacle to the electrification of our farms is the high cost of bringing electric service to them. It usually does not pay to tap a high-tension line and build a low-tension line to take care of the relatively small demand of a few scattered farms, but it frequently does pay to do these things to serve an industry; and when once a service connection is made and a line is built, neighboring farms can then be supplied with electric power at a reasonable cost. Hence, as small factories multiply in the rural districts, more and more farms will be electrified.

No one questions the great value of electric power to the farmer. Give the farmer electric power at a reasonable cost, and he can immediately relieve himself and his family of a large portion of their burden of labor, reduce his costs, make his profits more certain, and, what is of equal importance, raise his standard of living to a level corresponding to that of the city dweller, which will improve the morale of his family, help to keep his children at home and make it more easy for him to secure efficient labor when he needs it.

To sum up, the decentralization of industry will enable the farmer to broaden the earning capacity of his family, increase the business value of his farm and make his home more attractive. It appears, indeed, to be the most promising, if not the only practical influence that will bring agriculture back into step with other American industries and restore prosperity to it. If this can be done, it will mean the elimination of discontent and radicalism from a large and influential proportion of our population.

Abridgment of

The Quality Rating of High-Tension Cable With Impregnated Paper Insulation

BY D. W. ROPER[1] and HERMAN HALPERIN[1]

Fellow, A. I. E. E. Associate, A. I. E. E.

Synopsis.—*During the past five or six years, practically all of the American cable manufacturers have made some changes in their impregnating compound to produce cable having a low dielectric loss. In a number of cases, these compounds were not well chosen. During the same period, some of the operating companies have reduced the thickness of their insulation, resulting in increased dielectric stresses.*

In a number of cases the compounds, and perhaps also the paper that was used, developed faults that were more serious than high dielectric loss. Some cables have been very deficient in dielectric strength and others have developed a new type of trouble which has been termed "ionization;" after a comparatively short time, the operating voltage of such cable had to be materially reduced or the cable replaced, in order to keep the lines in service.

The cable manufactured during this period has generally passed, with a wide margin, the high-voltage tests required by the specifications. Occasionally a lot of cable which passes these tests by a narrow margin will be shipped by a manufacturer and, in such cases, the service record of the cable is unsatisfactory.

The investigations which form the basis of this paper consist of, (a) laboratory tests to determine what high-voltage tests cable, known to be of good quality, will withstand; as well as similar tests on other grades of cable. (b) A careful examination and dissection of samples of the cable as received from the factory and samples removed from lines which have failed in service or which have been in service for a number of years without failure. (c) A comparison of the operating records of the cable with the results of the dissection and examination of the samples and with the factory inspection and tests made on the cable before shipment. (d) Accelerated life tests on long samples of cable having a wide range in quality.

The results of these investigations have been correlated in a manner which permits of the determination of the relative quality of several lots of cable purchased, as well as changes in the specifications which must be made in order to secure satisfactory high tension cable with impregnated paper insulation.

* * * * * * *

INTRODUCTION

AFTER the first few years of experience with impregnated paper-insulated, lead-covered cables, it was thought that a solution of resin in resin-oil would be most suitable for the impregnating compound, and for a number of years this type of compound was used by practically all the American manufacturers, excepting one or two who instead, used a solution of resin in mineral oil. Cables operating above 7500 volts had a large dielectric loss and this caused many failures due to cumulative heating, and made it necessary to operate them at materially smaller currents than permissible on low-tension cables with no dielectric loss. Upon this point being brought to the attention of the manufacturers about 1917, changes were made in the impregnating compound, so that by 1923 the dielectric loss had been reduced to such an extent that its effect in reducing the carrying capacity became almost negligible.

The test results in recent years indicated that the thicknesses of insulation were more than necessary, and accordingly some of the large operating companies purchasing large amounts of cable made reductions in the thicknesses or increased the voltage rating for a given thickness, for the purpose of reducing cost and increasing line capacities, and *thus* increased the dielectric stresses.

The changes in the impregnating compounds and increase in the dielectric stresses developed a large amount of operating troubles on the newer cables, which made it necessary to replace them in some cases, and reduce the voltage in others.

Up to the time that troubles of this kind developed, it had been customary in this country for the cable manufacturers to supply cable to the larger operating companies under a five-year guarantee; and the manufacturers' expense, due to this guarantee, was very slight as most of the claims were due to defective workmanship in the factory or mechanical damage during shipment. The claims for dielectric loss failures were practically eliminated by the A. I. E. E. rule for maximum operating temperature of 85 deg. cent. minus E, with E as rated voltage in kv. About two years ago, the American manufacturers reduced their five-year guarantee to a maximum of two years.

The principal safeguard of the purchasers had rested in the five-year guarantee, as, for cables above 7.5 kv., normal operating voltage, the factory tests were quite perfunctory. The tests served merely to eliminate sections with very defective workmanship, but gave no clue to the quality of the insulation unless it was very bad indeed.

The situation to-day is not greatly different. High-voltage cable which will meet the requirements of all specifications which it has been possible to obtain and which are published in any country, may prove an utter failure within less than one year of operation at its rated voltage. Troubles of this character have

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1. Both of the Street Dept., Commonwealth Edison Co., Chicago, Illinois.

Presented at the Regional Meeting of the A. I. E. E., Madison, Wis., May 6-7, 1926. Complete copies available upon request.

not been confined to any one country, manufacturer, or operating company; several cases of such trouble have occurred within the year immediately preceding the presentation of this paper. High-voltage cables that have proved successful in service will pass all requirements of the most recent specifications by margins of the order of 30 to 100 per cent.

As some of the troubles take two or more years in developing, it is entirely possible for the guarantee period to expire before the trouble has become apparent, and then the operating companies are confronted with the proposition of replacing the cable at their own expense or operating it at a greatly reduced voltage. Therefore, the reduction in the guarantee period threw upon the operating companies, with the aid of the manufacturers, the responsibility of devising tests to be made upon the cable at the factory before shipment, to permit of a determination as to whether or not the cable will operate satisfactorily.

Some manufacturers stated that the troubles were due to imperfect impregnation and suggested an ionization test for the purpose of determining which cables were satisfactory. Such a test has been used in recent specifications. Further improvements were made by making moderate increases in the test voltages, but in spite of these slight changes the troubles continue.

This paper describes the methods which have been used in correlating operating experience on about 4,000,000 ft. of high-voltage, three-conductor cable

TABLE I

QUALITY RATING OF 500,000-CIR. MIL, THREE-CONDUCTOR, 13,000-VOLT CABLE

Item No.		Base Weight	Limits between which values were proportioned		Values for Various Manufacturers				
			Zero Weight	Full Weight					
	Manufacturer				*A*	*B*	*C*	B^1	*D*
	Year Made				1925	1925	1925	1922	1925-6
	A—Results of dissections and visual examinations								
1.	Workmanship on copper	4	Serious imperfections	No imperfections	2.0	3.0	2.5	3.0	4.0
2.	Workmanship on lead	2	Serious imperfections	No imperfections	2.0	2.0	2.0	2.0	2.0
3.	Workmanship on insulation and fillers	8	Serious imperfections	No imperfections	7.5	6.5	6.0	6.0	5.0
4.	Thoroughness of imprgenation	8	Poor throughout	Perfect throughout	7.0	7.0	4.0	1.0	7.0
5.	Tearing in bending tests	4	2 adjacent tapes at one point; 3 torn tapes per foot of cable	No tears	3.6	3.9	4.0	2.0	1.0
	B—Results of factory and laboratory tests on insulation								
6.	Ratio of max. to min. insulation resistance—for lots / —for sections	6	3.0 / 1.5	1.3 / 1.075	4.6	4.3	− 1.0	− 8.4	4.4
7.	Dielectric loss at 80 deg. cent, watts per foot	4	0.75*	0.075*	3.6	2.4	3.2	2.2	1.3
8.	Increase in power factor at room temperature from 20 to 100 volts per mil of insulation	8	0.02	0.00	3.2	0.6	0.2	0.0	2.2
9.	Puncture voltage on straight samples, kv	17	74.5	119.0	8.2	9.0	4.0	− 1.7	15.9
10.	Puncture voltage on cold bent samples, kv	18	65.0	104.0	21.2	22.6	8.3	− 8.8	26.3
11.	Ratio of item 10 to item 9	8	0.75	1.0	8.0	8.0	7.4	− 2.9	8.0
	C—General								
12.	Uniformity of insulation	13	Serious variations in quality of insulation	Reasonably uniform quality	11.0	11.0	6.0	7.0	11.0
	Total, Examination	26			22.1	22.4	18.5	14.0	19.0
	Total, Tests	61			48.8	46.9	22.1	−19.6	58.1
	Total, General	13			11.0	11.0	6.0	7.0	11.0
	Grand Total	100			81.9	80.3	46.6	1.4	88.1

*Corresponding power factors of dielectric are 10 per cent and 1 per cent at 60 cycles.

EXPLANATION

Items 1, 2, 3, 4 and 12, in the absence of definite limitations in the specifications, are based on arbitrary standards established for the guidance of the inspectors. The standards for zero weights would generally have caused the rejection of the cable had they been noted at the factory.

The figures for zero weight for Items 5, 6, 8, 9, and 10 are the requirements of the latest specifications under which the cable was purchased. Full weight is given for Items 6, 8, 9 and 10 for values which would give a large factor of assurance for these qualities. All of these values appear possible of attainment in the present state of the art.

Zero weight and full weight for Items 7 and 11 are about the extreme limits of current American practise. The reasons for Item 11 are given at some length in the paper.

In Item 6 the variation in insulation resistance is based on the largest ratios found for the insulation resistances in the lots of cable as submitted for inspection and tests by the manufacturer and also on the largest ratio of the insulation resistances of the several conductors of any given section in each lot. The weight for this item is divided equally between the values for the lots of cable and for the individual sections. The latter part would disappear for single-conductor cable.

The values for Items 1, 2, 3 and 4 were determined by the inspection at the factory plus information obtained during and after installation. The values for Items 6 to 10, inclusive, were based on the averages of the poorest 20 per cent of the test results. In Items 1, 2, 3, 4, 5, 8 and 12 the values given to each manufacturer were proportioned between zero and base weight and no negative values or bonuses were given on these items. In Items 6, 9 and 10 the values were proportioned arithmetically between zero and full weight and negative values were given if the results were poorer than the values for zero weight, and extra weight was given when the results were better than required for full weight. In Items 7 and 11, negative values were given if the results were poorer than required for zero weight, and no extra value was given if the test results were better than required for full weight.

All values are based on tests and inspection of cable received and accepted by the purchaser.

Note: At least 9 mi. of cable are represented in each of the above ratings.

TABLE II
QUALITY RATING OF 350,000-CIR. MIL, THREE-CONDUCTOR, 35,000-VOLT CABLES

Item No.		Base Weight	Limits between which values were proportioned: Zero Weight	Full Weight	Values for Various Manufacturers					
	Manufacturer				*M*	*N*	*O*	*P*	*Q*	*M*[1]
	Year made				1925	1924	1924	1924	1924	1923
	A—Results of dissections and visual examinations									
1.	Workmanship on copper............	3	Serious imperfections	No imperfections	2.7	3.0	2.3	2.6	2.5	2.0
2.	Workmanship on lead..............	2	Serious imperfections	No imperfections	2.0	2.0	2.0	2.0	2.0	2.0
3.	Workmanship on insulation and fillers	8	Serious imperfections	No imperfections	7.0	7.5	3.5	3.0	5.0	1.5
4.	Thoroughness of impregnation.......	8	Poor throughout	Perfect throughout	7.0	7.0	7.0	5.0	5.0	3.0
5.	Tearing in bending tests............	3	2 adjacent tapes at one point; 3 torn tapes per foot of cable...........	No tears	2.9	0.5	0.5	2.0	3.0	2.5
	B—Results of factory and laboratory tests on insulation									
6.	Ratio of max. to min. insulation resistance—for lots............... —for sections...........	6	3.0 / 1.5	1.30 / 1.075	6.0	4.8	5.9	5.3	0.3	−4.8
7.	Dielectric loss at 80 deg. cent.-watts per foot...........................	7	2.1*	0.35*	3.7	2.0	0.0	6.0	6.2	0.1
8.	Increase in power factor at room temperature from voltages of 20 to 100 volts per mil of insulation.......	8	0.02	0.00	3.3	0.4	0.0	0.4	0.0	0.0
9.	Puncture voltage on straight samples, kv.............................	17	160	256	17.7	16.3	7.1	2.3	−1.8	−1.8
10.	Puncture voltage on cold bent samples, kv..........................	17	140	224	20.2	12.1	12.1	10.1	−2.0	−3.4
11.	Ratio of item 10 to item 9...........	8	0.75	1.0	5.6	1.4	8.0	8.0	3.8	2.2
	C—General									
12.	Uniformity of insulation............	13	Serious variations in quality of insulation	Reasonably uniform quality	11.0	12.0	12.0	6.0	10.0	5.0
	Total, Examination...............	24			21.6	20.0	15.3	14.6	17.5	11.0
	Total, Tests......................	63			56.5	37.0	33.1	32.1	6.5	−7.7
	Total, General....................	13			11.0	12.0	12.0	6.0	10.0	5.0
	Grand Total......................	100			89.1	69.0	60.4	52.7	34.0	8.3

*Corresponding power factors of dielectric are 6 and 1 per cent at 60 cycles.
The same letters are used in Table II and Fig. 12.
The data were obtained from orders of several thousand feet of cable for columns *M* and *Q*; all other ratings represent several miles of cables.
The explanation under Table I also applies to Table II.

purchased in the past six years from ten manufacturers, with the specification requirements and test results so as to determine what changes and additions should be made in the present requirements.

The object of the investigation upon which this paper is based was to determine just what properties of the insulation were responsible for the failures of the cable in service and to indicate the changes that should be made in the cable specifications in order to materially reduce the number of service failures.

Outline of Methods

With such a complex material as impregnated paper insulation having a number of widely different and independent qualities or characteristics, it is practically impossible to compare the products of different manufacturers or different lots from the same manufacturer by any single measurement. The most feasible method of making a reasonably accurate comparison is to adopt the scheme which has been used by engineers with other types of material, that is, to assign weights to the various qualities in the light of past experience, and determine from test or inspection data the percentage of the maximum weight for each item which should be allotted to each manufacturer or lot of material.

Rating tables were first used by the authors to compare the quality of cable indicated by proposals from manufacturers, and later to compare cable actually shipped. At first the ratings were purely relative and did not permit a determination of the amount of improvement which the manufacturers made from year to year. To obtain this amount, the basis was later modified so as to make all of the comparisons on a fixed basis, which meant the adoption of a standard for each of the items considered. Tables I and II give such quality ratings for 13- and 35- kv. cables, respectively. Sixty-cycle current was used for all alternating-current tests.

During this period, it was the practise to make a careful examination of the cable immediately adjacent to each fault and also at the manhole ends of the same section of cable. A detailed study of the results of these examinations as the data accumulated and a careful comparison with the test and inspection data permitted the primary cause of the troubles to be determined. A reference to the corresponding test and inspection data then furnished a basis for determining the base weights for each item, a part of the limits between which the values were proportioned, and the values assigned to the several manufacturers for the various items in the tables.

A perfect method of rating the quality of cables would accurately predict their operating performance

over a wide range of quality of insulation and be equally applicable to the widely varying types of insulation now on the market. In the past few years there has been received cable ranging in quality from poor to excellent. The system of the Commonwealth Edison Company includes over 1300 mi. of 9- to 35-kv., three-conductor cable. For all of this cable the service records test and inspection data on the 800 mi. purchased during the past six years from 10 manufacturers were at hand. In making attempts to devise a quality rating method, each new constructive suggestion was tested by calculating a new rating table with the same original data in the endeavor to secure results which would at least rate the cables in their proper order of merit.

By carefully going over the operating records and comparing them with the test and inspection data and the results of examination of the cable near failures, the rating tables were altered and adjusted so as to bring the final results in accord with the operating experience.

While these studies were in progress, a series of tests had been undertaken to determine what high-voltage tests successful cable should withstand. After some data had been obtained, it appeared perfectly feasible to devise an accelerated life test so that the approximate life of the cable would be indicated by the time that the cable withstood the test. This resulted in another method of rating the quality of cables entirely independent of the first.

High-Voltage Tests

For many years it had been noted that the high-voltage tests which the cables actually withstood when tested at the factory were very much higher than the specification requirements. It had also been noted in a few lots of cable which had proved to be of inferior quality that the high-voltage test results were only slightly higher than the specification requirements. A series of high-voltage tests were, therefore, undertaken to determine what changes should be made in the specification requirements in order to eliminate such inferior lots of cable and, at the same time, allow the manufacturer a reasonable margin.

In the initial tests, the sections of cable were from 100 to 200 ft. long. Previous to applying the voltage, several thermometers were fastened to the lead sheath. With voltage on the cable, the sheath, which was grounded, was examined by the test operators about every 10 minutes, in order to detect points where the sheath temperature was higher than the remaining portions. At these points, which were called "hot spots," an additional thermometer was fastened to the sheath.

After failure occurred, portions of the cable including the fault and perhaps "hot spot" sections would be removed, dissected, and examined. The remaining portion of the length was again tested and this procedure was continued until the cable became too short for further tests. Usually three to seven tests were obtained on each original section of cable.

Several test voltage procedures were tried but most of the tests were made with an initial voltage of 3.6 times normal voltage. As this voltage made the tests unduly long for high grade 13-kv. cable, it was decided to increase the voltage 20 per cent after eight hours, and further increase the voltage 20 per cent after a second eight-hour period. Later, in order to obtain voltage-time curves, tests were made on samples from given sections of cable at a number of voltages maintained constant until failure occurred.

About 8000 feet of cable have been used in making some 250 such tests. The cable was about equally divided between new and second-hand cable. In selecting the sections of cable for these tests, samples were obtained from the cable that had been shipped by the several manufacturers. The sections of second-hand cable were selected so as to obtain similar data for cables of a wide range of quality whose service records were definitely known. The sections of cable used for this purpose were removed on account of failure, external damage, or changes in the transmission system.

Discussion of Quality Ratings

A. Workmanship

The first five items in Tables I and II can be considered under the general heading of workmanship. The information for calculating the values for these items was secured from the factory inspection reports and by examination of samples of cable taken from the ends of sections as received or from the middle of the sections whenever possible. Further information was obtained from time to time by the examination of samples of cable taken from sections removed on account of failures in service or other causes.

A large variety of defects in the conductors, lead, and insulation has been noted in these examinations, and values were assigned to the first four items in the rating tables on the basis of the influence of similar defects found at or near the points of failure which have occurred on test or in service.

Impregnation. The impregnation of paper-insulated cable is satisfactory when:

1. The compound is suitable for the purpose.
2. The impregnating process is performed to completely remove the air and moisture and thoroughly impregnate the insulation, filling all voids in the conductor and in the insulation.

Several tests have been evolved to determine whether the compound will be stable, but such a test was not included in the specifications for the cable covered by this paper. Therefore, Item 4 of Tables I and II refers to the completeness of the impregnation only.

The cable manufacturers contributed considerable discussion on the item of impregnation in commenting on the earlier rating tables, and apparently this dis-

cussion was warranted by the importance of the subject. No satisfactory explanation has been obtained for the marked differences found in the impregnation on the three conductors at one place in the cable nor for the large differences in impregnation throughout the length of one section.

When the insulation is examined near a point where failure, due to ionization has occurred, a pronounced difference in the impregnation is frequently found as,

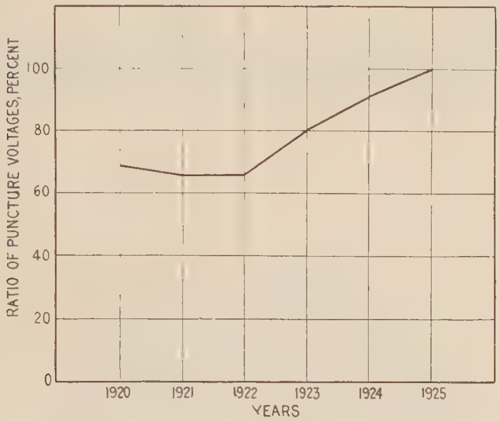


FIG. 1—CHANGE WITH TIME OF RATIO

Puncture voltage on cold bent sample
Puncture voltage on straight sample

for example, the insulation of one conductor filled with the evidences of ionization while the insulation of the other two conductors will be entirely free from such evidence. In other cases, many evidences of ionization will be found in the insulation of all three conductors near the point of failure, but will be entirely lacking in the manhole ends of the same section of cable.

Tearing of Paper Tapes in Bending Tests. The routine tests on the cable at the factory include a bending test on an occasional short sample that has been cooled to the minimum operating temperature which, for Chicago, is about minus 10 deg. cent. This is followed by a puncture voltage test and, later by an examination of the paper tapes in a three-foot section of the cable, cut from the middle of the bent portion. The number of tears of the paper tapes are noted and recorded.

During the past few years, the leading American manufacturers have made some marked improvements in the workmanship of the insulation as shown by the paper tapes being applied more smoothly and evenly, the number of torn tapes in the bending test considerably reduced, and the impregnation improved. The extent to which these improvements in workmanship have improved the quality of the insulation is indicated by the reduction in the effect of the bending test on the dielectric strength of the insulation.

The extent of this improvement is shown in Fig. 1 which gives the ratio of the puncture voltage, obtained on the samples that have been subjected to the cold bending test, to the puncture voltage obtained on the straight samples. During the past few years this ratio has risen from about 65 per cent to 100 per cent. It appears therefore that this ratio can be used as an excellent test for workmanship.

B. TESTS ON INSULATION

Insulation Resistance. The insulation resistance test is measured for each of the conductors of each section of the cable, and the greatest present use for the results is as an indication of the uniformity of the manufacturing processes. In Fig. 2 is shown the variation in insulation resistance of 125 consecutive reels as submitted by two manufacturers.

Figs. 3 and 4 show the variation of the power factor of the dielectric with the insulation resistance as obtained from 30 consecutive reels submitted by two manufacturers.

Fig. 5 shows similar data from two different lots of cable submitted several months apart by another manufacturer, and from such data and from other tests showing that no change in the paper was made during the same period, it is evident that the cable manufacturer changed the impregnating compound, a conclusion which has been verified by the manufacturer.

Dielectric Loss at 80 Deg. Cent. For uniformity, the dielectric loss at 80 deg. cent is used for comparison, although for 35-kv. cable it is realized that this is

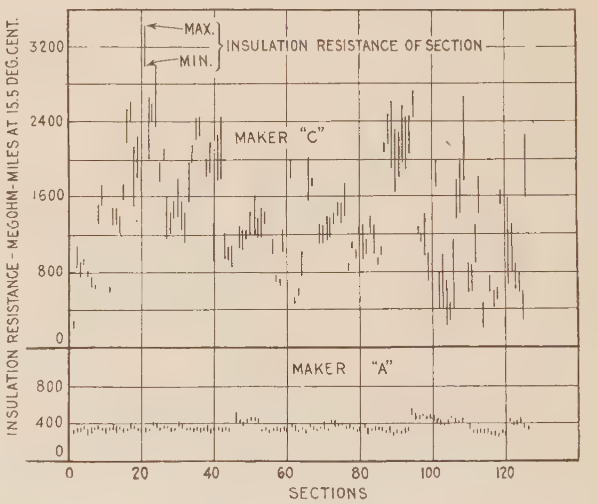


FIG. 2—INSULATION RESISTANCE VS. ORDER OF PRESENTATION OF SECTIONS

500,000-cir. mil, three-conductor, 13-kv. cable made in 1925
Note: The letters used designate the same manufacturer throughout the paper except for Table II and Fig. 12

above the standard maximum operating temperature. However, operating conditions occasionally arise which render it expedient to carry an abnormal load on a cable for a short time rather than open the line and cause interruption of service. The dielectric loss tests at 80 deg. cent. permit the heating of the cable under such abnormal conditions to be predetermined.

The manufacturers are now furnishing cable for voltages up to about 20-kv. with insulation of such

low dielectric loss that this loss does not reduce the carrying capacity of the cable more than one or two per cent. For practical purposes this may be considered negligible. The effect of the power factor of the dielectric on the permissible current loading of cables is indicated by the fact that if the power factor is five per cent then the dielectric losses of three-conductor 13-kv., three-conductor 35-kv., and single-conductor 132-kv., cables of the Commonwealth Edison Company are, about 0.37, 1.75, and 8.0 watts respectively per foot of cable. Since the maximum allowable copper temperature determines the total heat loss in the cable it follows directly that for commercial consideration, as the operating voltage increases, the maximum allowable power factor must decrease. Experience has shown that a dielectric loss of 1.75 watts per foot of the 35-kv. cable does not result in service failures due to cumulative heating. The recent product of some of the leading manufacturers has shown losses materially below this figure.

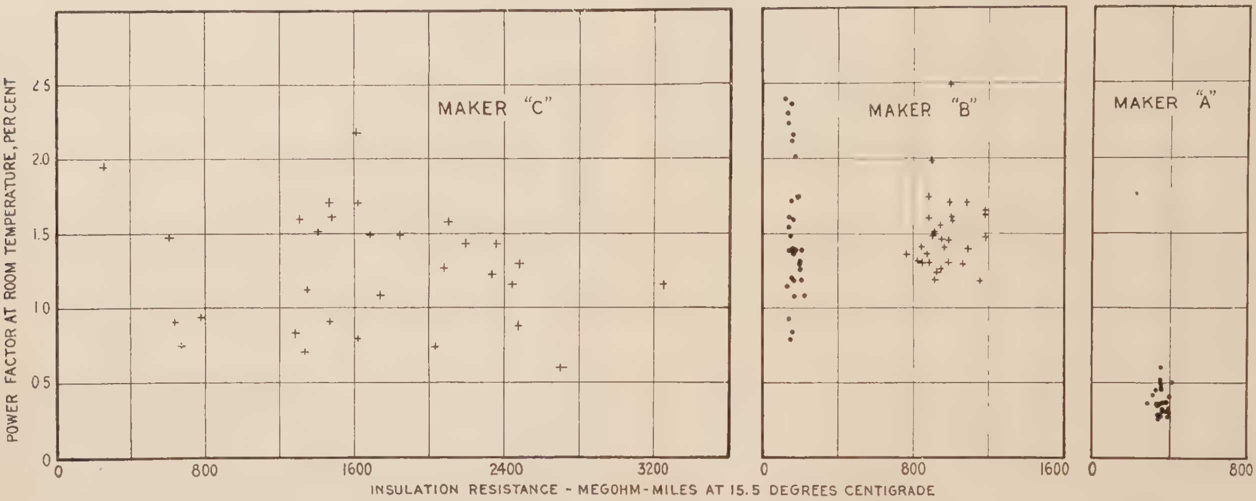


Fig. 3 Fig. 5 Fig. 4

Figs. 3-4-5—Power Factor vs. Insulation Resistance

For 500,000-cir. mil, three-conductor, 13-kv. cable, made in 1925 by three manufacturers.

Cables have 18/64 in. insulation between conductors and 14/64 in. insulation between each conductor and sheath

Power factor of dielectric is value obtained at room temperature on each section of cable at 100 volts per mil of insulation thickness. Insulation resistance is average for value for three-conductors obtained by the standard method with direct current

Data are shown for 30 consecutive sections of cable from makers C and A and for two lots of 30 consecutive sections, each presented several months apart, by maker B.

"Ionization" Test

A test made by measuring the increase in power factor over a certain specified range in voltage, say, from 20 to 100 volts per mil of insulation thickness, is called an ionization test. Several recent specifications require such a test on each section of cable.

Several European manufacturers contend that there should be no increase in power factor for about this change in voltage, while another manufacturer states that increases of one and two per cent for, respectively, single-conductor and three-conductor cables indicates satisfactory impregnation. Probably each statement is correct as applied to the particular combination of paper and impregnating compound in the cable from which the experience was obtained. Fig. 6 shows a number of curves taken from actual tests on samples of commercial cables made by manufacturers that are considered among the leading manufacturers in the world. Some of these cables having the greatest increase in power factor over the specified range in voltage have given the best service, while other cables having a very small increase in power factor have been found

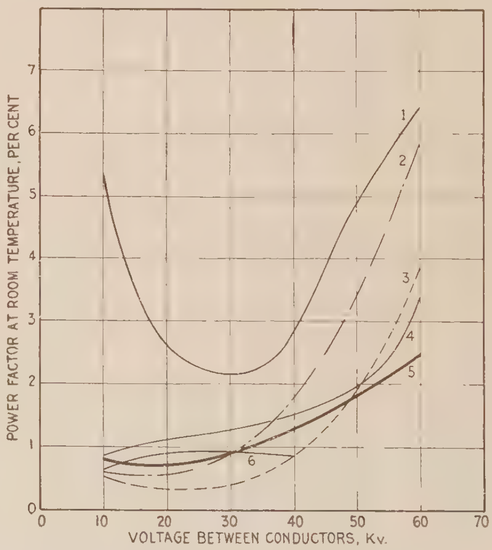


Fig. 6—Power Factor vs. Voltage

For 350,000-cir. mil, three-conductor, 35-kv. cables from various manufacturers

unsatisfactory for service at their rated voltage. In several cases, subsequent tests have developed proof that the impregnating compound was unstable, and this means that a test on the impregnating compound

itself is also necessary in order to insure satisfactory cable.

All these facts indicate the necessity of considerably more information before the proper limits for the increase in power factor can be fixed for the various types of insulation, so that all types will be equally satisfactory.

The visible evidence of high-voltage discharges or of ionization which are found upon dissecting the

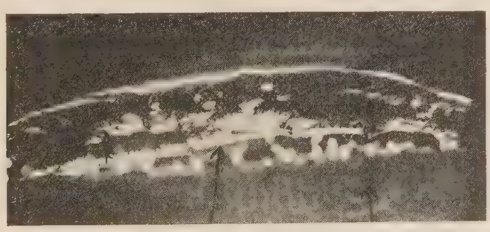
BLACK SPOT WAXY FLAKE

Fig. 7

Waxy flakes and black spots on center filler of three-conductor, 35-kv. cable, impregnated with a heavy grease. Cable was removed after being in service.

Fig. 8—Magnification (7) Diameters of Waxy Flake

Removed from space between adjacent turns of tapes of conductor insulation of same cable as in Fig. 7



STRIP OF WAX PAPER TAPE

Fig. 9—Photomicrographic Cut of (7) Diameter Magnification Showing Strip of Wax

Along edge of a tape of the conductor insulation of cable impregnated with a heavy oil

affected insulation, in the order in which they usually appear to develop in service, are:

a. Waxy flakes and black spots in the compound

b. Black and brown spots in the paper

c. Fern leaf or tree designs in the paper, and pin holes through the paper.

Figs. 7, 8 and 9 show evidences of these defects.

The evidences of ionization are generally found in the largest quantity where the stresses are the greatest, but their distribution throughout the insulation varies widely and appears to be affected by local variations in the impregnation. In the high-voltage tests on samples of cable, the waxy flakes develop only when the tests continue for a long time, of the order of 50 hours or longer; but the other evidences are developed by higher voltages in a much shorter time.

Dielectric-Strength Tests

High-voltage tests on each section of cable were never intended or considered as a test of the quality of the insulation, but were made for the purpose of

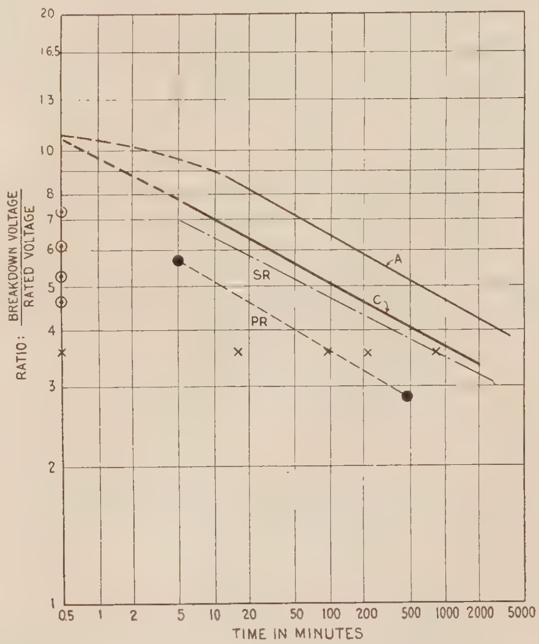


Fig. 10—Voltage-Time Curves for 500,000-Cir. Mil, Three-Conductor 13-Kv. Cables

Curves *A* and *C* represent results from tests on 20-ft. samples. Cable *A* appears quite satisfactory; cable *C*, inferior and non-uniform, as shown by wide variation in test results.

S R—Suggested test requirements

P R—Present test requirements. •Present specified tests

Typical test results on samples of cables that have proved unsatisfactory in service:

⊙Dielectric-strength tests at factory

×High-voltage tests in Chicago

eliminating sections having serious defects in workmanship. The first test required by American specifications to insure insulation of the proper quality was the requirement of dielectric-strength test on a short sample about seven years ago.

It has been found that 13-kv., three-conductor cables which met all the requirements of the specifications but which failed on the dielectric-strength test made in accordance with A. I. E. E. standards at a voltage below seven times normal, have been in general quite unsatisfactory. In order to obtain definite information on the proper dielectric strength requirements, a series of high-voltage tests were made on the recent products of two manufacturers, and the voltage-time characteristics thus obtained are shown by lines *A* and *C* in Fig. 10. There is also shown typical

results of dielectric-strength tests at the factory and accelerated life tests in Chicago obtained on cable that has proved unsatisfactory in service. Tests on the products of two additional manufacturers give results above line *A*. From these data and the data obtained in factory tests and tests previously described under the subject of High-Voltage Tests, it appears quite certain that if cable will pass the voltage tests corresponding to two or three well separated points on line *S R* in Fig. 10, it will have sufficient dielectric strength to give satisfactory service. However, the cable may be deficient in other respects; for example, in ionization. At the present time it is possible to secure cable from several manufacturers which will average at least 30 per cent higher than the tests so specified and at the same time leave the manufacturer a reasonable margin.

As will be noted from Fig. 10, the test results for the dielectric-strength test for 30 seconds were about the same for cables *A* and *C*, but at lower voltages cable *A* withstood a given test voltage about five times as long as cable C. These data show that the results obtained from a short-time dielectric-strength test are misleading as an indication of the quality of the insulation. In the past, considerable reliance has been placed upon such misleading information regarding the quality of the insulation.

The dielectric-strength tests at the factory and the tests previously described under the heading High-Voltage Tests, when correlated with operating experience indicate that

1. The short-time, dielectric-strengtht est should be made at seven times normal voltage for five minutes; or, if this test introduces pothead or terminal troubles, it will be equally satisfactory to make the test at six times normal voltage for 16 minutes.
2. Satisfactory results can be secured on the short-time test with a sample about 15 ft. long under the lead.
3. A long-time test should be made on samples of the cable, and the requirements for this test should be four times normal voltage for six hours.
4. In order to secure reasonably accurate results on the long-time tests in which the failure may be caused by irregularities that require time to develop, the sample should be about 75 ft. long.

All of the points above mentioned are on line *S R* Fig. 10, and if, for practical reasons, a slight modification is desired in some of these tests, they should be made in accordance with the line.

During the last few months, long-time tests at the factory have been made so as to secure additional information. The test requirements provide that the cable shall withstand 3.2 times normal voltage for eight hours, and the procedure has been that following this test, the voltage has been raised to 5.7 times normal voltage and continued until the cable failed. The samples tested to date have withstood the higher test voltage from about 2 to 12 hours. These data indicate that satisfactory cables which are now being made for 13-kv. service will readily withstand the proposed tests of four times normal for six hours, as well as the test of six times normal for 16 minutes.

The data for lines *A* and *C* were obtained from tests on cables in which the insulation was impregnated with a grease or a heavy oil and their use should be limited to such insulation. The lines indicate that the voltage varies inversely as the seventh root of the time and this law has been found to hold in tests made by F. M. Farmer. It is entirely possible that a different line would be obtained for cable in which the insulation was impregnated with a materially different compound.

Cold Bending Test

Bending-test clauses have been made a part of standard specifications to insure that the cable will not be damaged by the bending incident to its installation in the conduit and training in the manhole. In Chicago, the conditions require that cable installation shall proceed throughout the entire year, except during the very cold days of winter months; and so the specifications for this cable have called for bending tests at temperatures of about minus 10 deg. cent. The need for such a test is indicated by investigations made several years ago which have shown that in 3 per cent of the cable which is in the manholes there are about 20 per cent of the total failures.

Ratio of Puncture Voltage Tests

It has been mentioned under the heading *Workmanship*, that the ratio between the puncture voltage obtained on the sample subjected to the cold-bending test and the puncture voltage obtained on the straight sample, appeared to be an excellent test of workmanship. There is quite a variation in the results of the tests on individual samples; *e. g.*, the puncture voltage on the cold-bent sample is sometimes 10 or 15 per cent higher than that on the straight sample. A study of recent test data shows that if the ratio were required to exceed 75 per cent, it would necessitate good workmanship and still allow an ample margin for the variation between samples.

C. Uniformity of Insulation

This item is a recent addition to the rating tables. In the product of all manufacturers, deficiencies and irregularities are occasionally noted, and some of them can be eliminated only by conscientious workmen and efficient inspectors at the factory.

Non-uniform impregnation is the most common irregularity. Many failures have occurred at points in the cable where there was a marked deficiency in the impregnation. It would be of great assistance in eliminating sections of cable having such deficiencies and in reducing the number of failures which result, if some test which would be a measure of the minimum

quality of the insulation in any section tested could be devised and applied to each section of cable at the factory.

During the high-voltage tests made on three-conductor cable, it was noted that if the voltage was of the order of five or six times normal, a buzzing or crackling noise from the electrical discharges within the insulation could be distinctly heard. At some voltage, not well defined, the internal noise becomes inaudible and, at a voltage somewhat lower, the life of the cable becomes indefinitely long. The indications are that the failures of the insulation which occurred on high voltage tests were brought about by the effect of these internal discharges upon the insulation and that eventual failure of the insulation is inevitable, if the voltage is sufficiently high to cause these internal discharges. If, then, a test could be devised which would indicate the voltage at which the internal discharges begin, this would be an indication of the limiting voltage at the weakest point in the insulation throughout the section of cable tested. Such a test applied to each section of cable would be an invaluable addition to the tests now available, as it would give a direct indication of the minimum quality of any section of cable, whereas, the best that can be accomplished with the present ionization test is to determine the average quality.

The variation in impregnation, plus local defects in workmanship and the resulting variation in the quality of the insulation in a section of cable have been the cause of many failures in service during the last few years in cable that had passed, with a wide margin, all of the requirements of the specifications. Similar variations have been frequently indicated by the results of accelerated life tests on sections of cable; and these tests have shown that if a portion of cable, a few feet long, was removed from a long section of cable, then the voltage rating of the remainder, with the same factor of safety, could be increased by amounts ranging from 15 to over 100 per cent.

Hot Spots

Further evidence of the non-uniformity of the insulation is contained in the record of the hot spots on the lead sheath in the high voltage tests. These hot spots were distributed with great irregularity along most of the sections of cable tested. The temperature of the lead sheath at these hot spots ranged from two or three deg. cent. up to 74 deg. cent. above adjacent portions of the sheath.

In tests on one section of the cable, sudden temperature rises of about eight deg. cent. developed in less than 10 minutes in two hot spots, accompanied by loud crackling and buzzing noises, followed by a disappearance of the noises, and a decrease of about eight deg. cent. in the temperatures. Then the temperatures increased five deg. cent. slowly to the end of the test, when failure occurred elsewhere. A broken filler was found at one of these hot spots.

As the location of the hot spots was recorded by reference to marks made on the original section of cable, it was possible to determine whether the hot spots would reappear at the same locations after an interruption of the test. Sixty per cent of the hot spots which developed in the first tests on 13-kv., three-conductor cable reappeared on subsequent tests. For the 33-kv., three-conductor cable, the corresponding figure was 84 per cent. In those tests where failure was in the cable and the time of the test was sufficient to result in hot spots of two deg. cent. or more above the minimum sheath temperature, 74 and 53 per cent of the failures occurred in hot spots for, respectively, the 35- and 13-kv. cables; 41 and 27 per cent, respectively, of the failures were at the maximum hot spots.

The study of all records shows that, in general, the cable manufacturers that have the best control of their materials and manufacturing processes, as evidenced by the uniformity of test results and inspection data, make the best cable.

Stability of Impregnating Compound

Recently it has been discovered that certain previously used impregnating compounds are entirely unsuitable for use in high voltage cables, that is, cables with average stresses exceeding about 40 volts per mil, and that when such compounds are used, the most perfect process of drying, vacuum treatment and impregnation will not prevent rapid deterioration of the insulation. F. M. Farmer[2] has devised a test which will indicate the relative stability of compounds. From his data it appears feasible to devise a clause for specifications which will eliminate unstable compounds. A large number of failures of the 35-kv., three-conductor cable can be directly traced to this cause as well as a smaller number of failures occurring on 22-kv. and 13-kv., three-conductor cables.

Comparison of Quality Ratings with Accelerated Life Test Results

The relation between the quality ratings given in Table I and the results of the accelerated life tests made upon sections of the same cable is shown in Fig. 11. The variations of the individual points from the curve as drawn are no greater than might be expected from the variations in the quality of the insulation. As the accelerated life test for those cables having a life of only a few years has been found to be a fairly accurate indication of the service record of those cables, it appears that the curve in Fig. 12 verifies the results of the quality rating table, as a prediction of the service records of the cables of widely varying quality.

As the zero base weights in Table I practically correspond with specification requirements, Fig. 11 indicates that if the cable passes the specifications with a narrow margin, it will be unsatisfactory in

2. "Tests on High-Tension Cable," by F. M. Farmer, presented at Regional Meeting of A. I. E. E. at Madison, Wisconsin, on May 6-7, 1926.

service, and this indication is confirmed by experience. In the tests at the factory for cable *B'*, the dielectric-strength tests were passed by a narrow margin, and there was a high percentage of failures in the voltage test on each section; there were several failures, both in the test after installation and in the first few months of service. A very similar experience was had with another manufacturer. A study of the rating table clearly indicates the changes in the specifications that must be made in order to eliminate such cable by means of the factory tests.

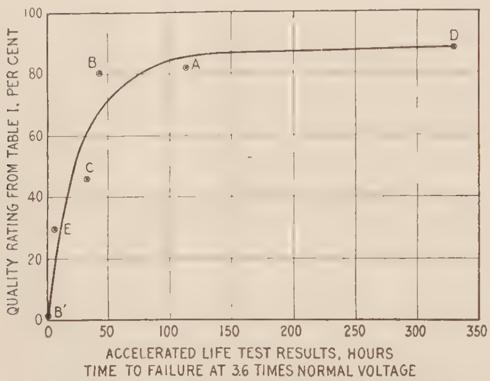


FIG. 11—RELATION OF QUALITY RATINGS WITH ACCELERATED LIFE TEST RESULTS, FOR 500,000-CIR. MIL, THREE-CONDUCTOR, 13-KV. CABLES

Tests which were at 46 kv. and higher were evaluated for 46 kv., which results in a maximum dielectric stress of about 72 kv. per cm.

Cable *E* was of slightly higher quality and gave somewhat better results in the factory tests and in service. Cable *C* was of still better quality, but the quality as indicated by inspection and all of the tests was very irregular. About 10 miles of this cable was installed and placed in service last fall, and one service failure, which was due to no apparent cause, occurred within two months.

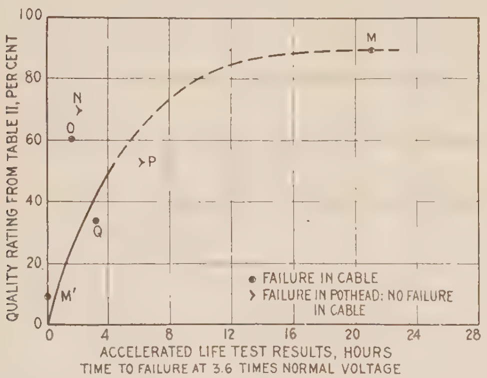


FIG. 12—RELATION OF QUALITY RATINGS WITH ACCELERATED LIFE TEST RESULTS, FOR 500,000-CIR. MIL, THREE-CONDUCTOR, 35-KV. CABLES

Tests were at 127 kv., which results in a maximum dielectric stress of approximately 125 kv. per cm.

Cables shown by *A* and *B* and installed last fall have had no failures in service. The quality of these cables appeared so high that lengths of about 300 ft. each were installed on 25-cycle, 20-kv. lines last fall in order to verify the quality rating as determined from the table. No failures on these test lengths have occurred to date.

Table II is a rating similar to Table I for typical examples of several different grades of 35-kv. cable which have been received to date. Fig. 12 shows the relation between these quality ratings and the accelerated life test results. Several of the cables represented have proven unsatisfactory for operation at 35-kv.; they developed the signs of ionization previously described and tests on their impregnating compounds show that they would have been rejected by Mr. Farmer's test for stability. The curve in Fig. 12 cannot be drawn with as much accuracy as the curve in Fig. 11, but Table II and Fig. 12 appear to indicate necessary changes in the specifications to insure satisfactory 35-kv., three-conductor cable.

As supplementary to the quality rating tables, the accelerated life tests appear to be a great aid, since they have revealed that even the best cables in Tables I and II still have irregularities; for instance, protruding strands of the conductor, and misplaced and broken fillers. If the tests are made on 13-kv. cable at about four times normal voltage, the results show:

1. Cable of very poor quality will usually fail within a few minutes without any visible signs of deterioration upon examination.

2. Cable of somewhat higher quality which lasts about one-half hour will develop hot spots showing irregularities in the cable, and may also develop slight tree designs and black spots.

3. Cable which will withstand this test for several hours will develop tree designs and black spots accompanied occasionally by punctures through one or more of the layers, perhaps some distance from the test failure; and the temperature of the sheath will rise about 10 to 90 deg. cent. above ambient temperature.

4. In cable of such a quality that it will withstand the test for about 50 to 100 hours, tree designs will usually be more advanced, and if the compound is unstable waxy flakes will probably be formed.

It is recognized that Table I and II are not perfect. They can never be made more accurate than the data from which they are developed, and these data will always vary in accordance with the non-uniformity of the insulation. Changes in the rating tables will be required as additional information is secured and especially to permit the tables to be properly applied to some of the new types of insulation which are now being developed. However, there appears to be no reasonable doubt as to the feasibility of using the quality rating methods outlined in this paper as a basis for modifying the specifications in order to secure cable of the desired quality.

Conclusions

1. All high-voltage tests on samples should be continued until failure occurs.
2. Long-time tests at several times normal voltage should be made on samples of the cable at the factory.
3. A test requirement should be inserted in high voltage cable specifications to prevent the use of unstable impregnating compounds.
4. The ratio of the puncture voltage obtained on the cold bent sample to the puncture voltage obtained on the straight sample appears to be an excellent test of workmanship.
5. A test is needed to indicate the minimum impregnation in a section of cable.
6. The best cable is, in general, made by the manufacturers that have the best control of their processes, as indicated by the uniformity of test results and inspection data.
7. If tests on three-conductor, high-voltage cables are of sufficient duration to develop hot spots, it has been found that (a) a majority of the cable failures will occur in hot spots and about one-third of these failures will be in the maximum hot spots; (b) a majority of the hot spots will reappear in subsequent tests on a given section of cable.
8. Higher quality of the insulation is necessary as the operating voltage increases.
9. If the compound is stable, and test and inspection data are properly correlated with operating experience, then quality rating tables can be used to predetermine with reasonable accuracy;
    a. The relative merits of several different types of insulation or lots of cable.
    b. The service record of any particular lot of cable.
10. Accelerated life tests made at suitable voltages followed by careful dissection and examinations of the insulation give consistent results which confirm the quality rating tables.

The authors gratefully acknowledge the efficient assistance they have received from C. E. Betzer, K. W. Miller, Karl Horine and L. B. Schofield in securing and correlating the information on which this paper is based.

Abridgment of

Dielectric Absorption and Theories of Dielectric Behavior

BY J. B. WHITEHEAD[1]

Fellow, A. I. E. E.

I. Introduction

Of the various component parts entering into electrical systems of all characters, the insulation is the least susceptible to exact computation and design. In few, if any cases of even simple and pure materials are the dielectric properties, resistivity, dielectric strength, specific inductive capacity, either constant or uniform; and in the cases of composite and fabricated insulations of manufacture the variations are extremely wide. As results, in all cases liberal factors of safety to cover the worst probable conditions must be allowed, resulting further in increased size and cost, and in undesirable magnitudes of other properties, such as dielectric loss and phase difference, volume and surface conductivity, circuit capacity and conductance, etc. Little if any attempt has been made to control the inherent characteristics of simple dielectrics, or to study their influence in combinations. Physicists appear to have all but forgotten the unsolved problems of dielectric behavior, or perhaps to have given them up. The control of manufactured insulation appears to be limited to heat treatment, principally for the purpose of elimination of moisture—a sufficiently important object—and to the obtaining of pure raw materials. Studies of the properties of these materials in their bearing on those of the composite final form of the insulation have not appeared in any quantity.

The Committee on Electrical Insulation of the Division of Engineering and Industrial Research of the National Research Council was formed for the purpose of pointing out the directions in which research in this field would be most profitable, and if possible to propose a plan for concerted experimental attack.

The literature describing work already done on dielectrics, from the points of view of both theory and practise, is enormous in volume. Many important data are hidden in this mass, as well as much careful and competent theoretical analysis. In order, therefore, to have as clearly as possible before it the results of all this work, the Committee has deemed it its first important duty to review the entire literature of dielectrics and insulation and to attempt to gather together the important results of the work of others into a series of reviews; and further, to draw from these

1. Professor of Electrical Engineering, Johns Hopkins University, Baltimore, Md.

Presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926. Copies of complete paper, including bibliography, available upon request.

reviews conclusions as to the most promising directions for future work.

II. Historical Outline

Dielectric theory may be said to have had its origin in the work of Cavendish[2] (1773). Although looking for different values of induced charges amongst various substances, and not apparently noting the distinction between conductors and dielectrics, he nevertheless showed clearly the influence of the specific inductive capacity of the latter, and his measurements give a scale of relative values.

Faraday's elaborate studies on the exact equality between inducing and induced charges on concentric conductors, with and without dielectrics and conductors between them, led to his famous conception of a point to point transference through the medium of the influence of an electric charge, at a point, or on a conductor, at a distance. Following immediately therefrom are his well-known ideas of lines of force, tubes of induction, and dielectric polarization. Maxwell's matchless genius appreciated the importance of Faraday's work and theory, and saw the applicability of the theory of potential, as already developed by Poisson for the magnetic field. Maxwell introduced the conceptions of volume distribution of charge—the polarized molecule—as the active part of the medium demanded by Faraday, electric displacement and its magnetic effect, and built up the theory of dielectric behavior which has ever since constituted without rival, the foundation of all subsequent physical research, and of all electrical engineering applications.

The outstanding features of the theory thus briefly outlined, are the idea of dielectric polarization as developed by Faraday, and Maxwell's generalized analysis of the dielectric field. The treatment built up assumes constant values for dielectric susceptibility and specific inductive capacity, and it is interesting to note that these assumptions are common today in elementary text books, and even in more advanced treatises, in spite of our long knowledge of the limitations pertaining to such a view. The explanation is apparently found in the facts that a few substances show little or no dielectric absorption, and so constant values of susceptibility, and that with care in preparation, the error arising from dielectric absorption may be reduced for many substances to small value. In other words, it seems to be generally assumed that the phenomenon of dielectric absorption, which is not accounted for by fundamental theory, is an anomalous property of certain dielectrics, which would probably disappear if sufficient care were taken in the elimination of impurities. As a matter of fact, however, there are few substances which show no absorption, and many show it in conspicuous degree. Absorption, therefore, should rather be considered a normal property of all dielectrics, although not yet rigidly susceptible to expression in terms of fixed constants or definite functions.

2. A bibliography of all work referred to, and classified by subject will be found at the end of the complete paper.

Dielectric absorption made its appearance in the very earliest days of electrostatic experiment in the residual charge of the Leyden jar (1746). It is described at some length in the experiments of Benjamin Franklin (1748). It was thus well recognized by Faraday and Maxwell. In fact, as well known, Maxwell gives us the first attempt at a theoretical explanation, in terms of the normal constants of specific resistance and specific inductive capacity, as described in further detail below.

III. Dielectric Absorption and Related Phenomena

We may conveniently describe the phenomenon of dielectric absorption, and other allied properties of dielectrics in terms of the behavior of a simple parallel plate condenser.

Since it is probable that no dielectric or insulator exists which is entirely free from conductivity, it has been customary since Maxwell's classical analysis, to consider that in all dielectrics the polarization and conduction currents are superposed on each other. We may, therefore, extend our definition of a "normal" dielectric to include also the property of conductivity. Therefore, in the above case we must also recognize the presence of a conduction current, i_g, added to the charging current $i_1(t)$.

Dielectric Absorption as Observed in Experiment. Referring to our elementary condenser, the application of continuous voltage is followed by the instantaneous charging of the geometric capacity, current $i_1(t)$, a conduction current, i_g, which may or may not obey Ohm's law, and a slowly decaying "anomalous," or "absorption," or "residual" current, $i_1^1(t)$. If this current, $i_1^1(t)$, is all of "reversible" type as is usually the case in solid dielectrics, it builds up the stored or residual charge, $Q_1 = \int_0^t i_1^1(t) \,.\, dt$, which after the initial discharge of the geometric capacity, appears as the building up of a difference of potential between the plates if the condenser stands open, or as a slowly decaying discharge current giving a charge, $Q_2 = \int_0^t i_2(t)\, dt$, if the condenser is short-circuited. In such cases (*i. e.*, if $Q_2 = Q_1$), $i_1^1(t)$ will be called the "reversible absorption current." In liquid dielectrics there is also a steadily decreasing residual current $i_1^1(t)$, but this does not in general obey the same laws as in the case of solids, and in nearly all cases there is no corresponding discharge current $i_2^1(t)$. In such cases $i_1^1(t)$, will be called the "irreversible" absorption current.

The Reversible Absorption Current. This is the

absorption current commonly observed in good solid insulators, free from moisture, and there is good experimental evidence that the charge and discharge currents have the same form *i. e.*, in equation (2) $i_1^1(t) = i_2^1(t)$. Systematic and reliable studies of the mode of the variation of the absorption currents of charge and discharge, may be said to have begun with Kohlrausch (1854). They received a great stimulus in the experiments of Sir John Hopkinson who made extensive studies in the period 1876 to 1897, and in which he appears to have had the benefits of Maxwell's advice (Paper No. 19). Maxwell was deeply interested in the phenomena in dielectrics and treats them at great length.

Kohlrausch, Hopkinson, Giese, J. Curie, Schweidler, Shuddemagen, Jordan, Tank and others have found that the time variation of the reversible absorption current may be expressed with close accuracy by the empirical formula:

$$i_1^1(t) = a\,t^{-m} \tag{3}$$

Others have found that the following formulas express their observations more closely:

By J. Curie, Malcles, Wagner, Steinmetz:

$$i_1^1(t) = a\,e^{-bt^n} \tag{4}$$

By J. Curie, von Schweidler, H. A. Wilson:

$$i_1^1(t) = \frac{a}{1 + b\,t} \tag{5}$$

By Trouton and Russ:

$$i_1^1(t) = \frac{a}{b + t} + c \tag{6}$$

By Fleming and Dyke, Thornton:

$$i_1^1(t) = a\,e^{-bt} + c \tag{7}$$

General Formula. With change in the value of the applied voltage, or of the thickness of the dielectric, the time rate of variation of the current is unchanged, but the values are increased in proportion to the voltage gradient (Curie, Wilson). The stationary final value of the charging current also obeys Ohm's law in most cases, and so may be considered as a normal conduction current. In a few cases, this conduction current is either absent or negligibly small, although the absorption may be quite large; *e. g.*, ebonite (Gaugain, Malclés). Generally, therefore, we may write:

$$i_1^1(t) = B\,.\,C\,E_0 = \varphi(t) \tag{8}$$

in which B is a constant and $\varphi(t)$ a definite function for the material of the dielectric, and C the geometric capacity proportional to the area and inversely as the thickness.

Temperature has a marked influence on the absorption current. There is universal agreement, that temperature increases both the currents $i_1^1(t)$ and $i_2^1(t)$, as well as the final conduction current.

The Principle of Superposition. One of the earliest features noticed in the phenomenon of residual charge was the occasional reversal of its sign as related to the foregoing charge. Hopkinson (Papers No. 18 and 19) studied this property in glass at great length.

The following more exact statement of the principle of superposition is due to von Schweidler: After any change, ΔE, in the voltage, the actual observed current takes on an additional term, and is made up of a term representing the undisturbed variation of the original current, and a superposed current which so varies as though a voltage of the absolute value of the change in voltage, ΔE, had been applied to the uncharged condenser. If, therefore, at time $t = 0$, the voltage E_0 is applied, and then at times t_1, t_2, t_3, etc., any positive or negative changes of voltages $\Delta_1 E$, $\Delta_2 E$, $\Delta_3 E$ are applied then we have as the value of i_1^1 at any instant t.

$$i_1^1(t) = B\,C\,[\,E_0\,\varphi(t) + \Delta_1 E\,.\,\varphi(t - t_1) + \Delta_2 E\,.\,\varphi(t - t_2) + \,.\;.\,] \tag{9}$$

Obviously the conduction current is not included in the above expression. Thus, if the final conduction current is subtracted from the charging current, it is seen that the equality of the reversible charge and discharge currents ($i_1^1 = -\,i_2^1$) is merely a special case of the principle of superposition.

Still more generally it follows, if the principle of superposition be true, that for any continuous variation of the voltage as expressed by the function $E(t)$, the reversible absorption current is given by:

$$i_1^1(t) = B\,C\,.\int_0^t \frac{d}{d\,u}\,(E(u))\,.\,\varphi(t - u)\,d\,u \tag{10}$$

in which t is the instant at which $i_1^1(t)$ is measured and u is the elapsed time controlling the variation of E. We shall see that formula (**10**) is of great importance as a means for computing the value of dielectric loss due to alternating electric stress.

IV. Theories of Dielectric Phenomena

Theories of Dielectric Absorption. Ever since the phenomenon of residual charge was recognized there have appeared suggestions and hypotheses as to the general nature of the underlying processes. Beginning with mere suggestions in the early days, as for example, the slow penetration or "soaking in" of the charge, (readily shown to be untenable) they have increased in elaboration and complexity as further knowledge of the phenomenon has been gained. In reviewing these theories today we are presented with such pictures as a viscous yielding of the dielectric, frictional motion of molecules and electrons, infinitesimal conducting particles embedded in insulating sheaths, the free motion of electrolytic ions, dielectric hysteresis, the capillary motion of water, etc. It is impossible within a limited space to give a complete view of all these theories. It appears best, therefore, to attempt their classification into a few groups and to give one or two conspicuous examples in each group, with some attempt to outline the reasoning and evidence in support.

Most physicists offering explanations of absorption have apparently considered that the observed phenomena in anomalous dielectrics are not consistent with the fundamental equations of the electromagnetic field, and have built other equations based on new special properties of the dielectric, not embraced in the older theory. There is, however, one conspicuous instance, that of Maxwell, in which the fundamental equations are taken as a basis. We may, therefore, select two of our groups in accordance with these two views, and add a third to include those looking to present theories of the internal structure of the atom as bases for the explanation of dielectric behavior. There is also a possible fourth group as proposed by von Schweidler, in which anomalies of conductivity are invoked, but the evidence in support is not so strong as in the other groups.

Our classification of theories of dielectric absorption is then as follows:

1. Those in which the fundamental magnetic equations are retained, and the anomalies of dielectric behavior are attributed to anomalies of the structure of the dielectric medium.

2. Those in which the departures from the fundamental laws are attributed to anomalies of dielectric displacement without reference to underlying mechanism. Dielectric displacement is not proportional to field strength, but dependent on the preceding state of the dielectric.

3. Explanation of displacement and its anomalies is traced to the motion of electrons within the atom.

4. Explanations based on anomalies of conductivity, such as the free motion of ions, electrolytic dissociation, water in bulk or in capillary filaments.

Group I

Maxwell. All students of dielectric theory are familiar with Maxwell's treatment of absorption. He starts with the assumption that all dielectrics have both specific inductive capacity and conductivity as we know them in normal dielectrics, and that under electric force they function simultaneously and independently of each other. The assumption is justified by the experimental facts that conductivity may be observed in even the best insulators, and that poor insulators with very high conductivity also manifests specific inductive capacity. No further assumptions, as for example as to the origin of these properties, are necessary in Maxwell's development.

For simplicity he then assumes a dielectric as built up of a number of plain strata of different materials of thickness a_1, a_2, etc., stating that a medium formed of a conglomeration of small pieces of different materials would behave in the same way, although the case is not susceptible of exact analysis. The obvious assumption then is that every dielectric which shows absorption consists of a mixture of two or more different materials, even though under our closest examination it may appear to be homogeneous. Considering unit cross section, let X_1, X_2, etc., be the electric intensities in the several strata, f_1, f_2, etc., the displacements, k_1, k_2, etc., the reciprocals of the specific inductive capacities, r_1, r_2, etc., the specific resistances, p_1, p_2, etc., the conduction currents, and we have at any instant:

$$p_1 = \frac{X_1}{r_1} \tag{11}$$

$$f_1 = \frac{X_1}{r \pi k_1} \tag{12}$$

and

$$u = \frac{X_1}{r_1} + \frac{1}{4 \pi k_1} \frac{d X_1}{d t} \tag{13}$$

in which u is the current in the outer circuit and so in each layer. Similar equations hold for the other layers. The total e. m. f. on the condenser is the sum of X_1, X_2, X_3, etc. From equations (**13**) the X's may be evaluated as similar functions of u, in terms of the different values of r and k, and so an expression may be had for u in terms of E, *i. e.*, the charging current of the condenser as function of E, the constants of the material and the time t. Maxwell does not derive this expression, but states that if there are n layers of material having *different values of the ratio* $r : k$, the combined general equations (**13**) will form a linear differential equation of the nth order with respect to E, and the $(n - 1)$th order with respect to u, t being the independent variable. He also shows that if the ratio $r : k$ is constant for all layers the case reduces to that of a homogeneous dielectric.

Experimental evidence in favor of Maxwell's theory is very meager, and chiefly limited to indirect and broadly qualitative confirmatory observations. Cohn and Arons tested the assumption that polarization and conductivity occur independently by means of parallel condensers of different dielectrics and found good agreement. Mixtures of xylol and anilin showed a 10,000 fold variation of resistance with only a ⅓ variation of dielectric constant. Rowland and Nichols showed that in perfect samples of calcite and possibly quartz, probably the most nearly homogeneous substances available, there is no absorption. Hertz showed that benzine, a homogeneous fluid, when impure shows absorption, which disappears on purification. Arons claimed that carefully purified paraffin shows no absorption; this is disputed however by Dessau and others. Wagner finds extremely low values of power factor at 5000 cycles for ceresin and paraffin, but that for a 50 per cent-50 per cent mixture the power factor was increased several times. Muraoka by careful purification found no absorption in parraffin oil, petroleum, resin oil, turpentine and xylol. For layers of air and paraffin absorption appears. Many observers have found that the observed curves of charge and discharge currents, while not obeying the exponen-

tial law with a single term, can nevertheless be represented readily by several such terms, as called for in Maxwell's most general case. The principle of superposition as observed by Hopkinson and Curie has been shown by von Schweidler to be a necessary consequence of Maxwell's theory. However, its firmest basis is found in the fact that it introduces no new phenomena nor assumptions, but relies only on properties of matter already well known, and on fundamental electrodynamic equations. This, more than any experimental confirmation, accounts for the firm hold that this theory has on the mind of the physicist of today.

The chief disadvantage that the theory suffers is that it not only has had no quantitative nor exact experimental confirmation, but many experiments appear to offer actual contradiction. Many observers have found other expressions than the exponential for the absorption current, of whom particular mention may be made of Curie, Fleming and Dyke, and Trouton and Russ.

Wagner. Maxwell's development assumes successive layers of different dielectrics, each having different values of r and K. Many layers must be assumed to account for the results of experiment, and this leads to mathematical difficulties. The charging curve for two substances obeys the negative exponential relation to the time as already noted. Using this relation K. W. Wagner examines the curves taken on various substances, and states that only a very few exponential terms are necessary in any case to account for the curves of experiment, and moreover that the time constants of these terms group themselves more or less closely about a principle value T_0.

Group 2. Theories Based on Anomalous Displacement

As the phenomena of anomalous charge and discharge were known long before the discovery of the electron and ionic conductivity, it is natural that early theories as to their causes should have taken the form of analogies with other elastic and viscous phenomena. Thus, one of the earliest, that of Hopkinson, adopted the relations found in the elastic residual properties of ordinary materials under mechanical distortion. Electric displacement is assumed analogous to mechanical displacement. But electric displacement in the fundamental theory is proportional to the electric intensity, and not so in anomalous dielectrics, and so practically all the theories in this class assume a more or less complicated relation between the field E and the displacement D, and of such a kind that D is determined not alone by the instantaneous value of E, but also by the foregoing condition of the dielectric. Such relations exist between deformation and force in elastic media, and between induction and field strength in magnetic media.

Pellat considers the displacement as divided into two parts. The first is that of the fundamental theory:

$$D^1(t) = \frac{K}{4\pi} E(t) \tag{19}$$

the second part $D''(t)$ is assumed to obey the equation

$$\frac{d\,D''(t)}{d\,t} = \alpha\,[\,D''(\infty) - D''(t)\,]$$

$$= \alpha \left[\eta \frac{K}{4\pi} E(t) - D''(t)\right] \tag{20}$$

that is that D'' tends to a final value $D(\infty)$, proportional to E, and the rate of change of D'' is always proportional to its difference from the final value. Pellat calls D^1 the "fictitious" and D'' the "true" polarization; Schweidler, who has developed this theory further prefers the terms "normal" and "viscous" displacement.

Thus for constant E_0 and $t > 0$ we have:

$$D''(t) = \eta \frac{K\,E_0}{4\pi}(1 - e^{-\alpha t}) \tag{21}$$

$$i_1{}^1(t) = \frac{d\,D''(t)}{d\,t} = \alpha\,\eta \frac{K}{4\pi} E_0\, e^{-\alpha t} \tag{22}$$

and the function showing the time variation of the reversible anomalous current takes the simple negative exponential form.

By integration of the above equation, we have for any type of variation of the electric force $E(t)$, remembering the principle of superposition

$$D''(t) = e^{-\alpha t} \int_0^\infty \alpha\,\eta \frac{K}{4\pi} E(u)\, e^{-\alpha u} \,.\, d\,u \tag{23}$$

$$= \alpha\,\eta \frac{K}{4\pi} \int_0^\infty E(t - \omega)\, e^{-\alpha\omega} \,.\, d\,\omega$$

and so:

$$D(t) = \frac{K}{4\pi} E(t) + \alpha\,\eta \frac{K}{4\pi} \int_\infty^t E(t - \omega)\, e^{-\alpha\omega}.\, d\,\omega \tag{24}$$

Thus, the variation of the displacement satisfies the principle of superposition, and the theory of Pellat is seen to be a special case of that of Hopkinson, in which $\varphi(\omega)$ is proportional to $e^{-\alpha\omega}$.

The simplicity of Pellat's assumption as to the variation of the displacement, and the close approximation to observations which results in the form of the anomalous charging current, make a strong appeal, in spite of the absence of all suggestion of underlying explanation. In order to supply this deficiency, von Schweidler has extended Pellat's proposal in considerable elaboration, with the aim first to bring it more nearly into accord with observation, and second to present a picture of underlying mechanism.

As regards experimental confirmation Grover, with a-c. studies of paper condensers, concluded that of several theories examined, the Pellat theory as modified by von Schweidler was the only one that could be made to give quantitative results in agreement with the obser-

vations. The quantities studied were changes in capacity and phase difference, with frequency and temperature. It is to be noted, however, that Grover did not examine Maxwell's theory as extended by Wagner, which appeared later, and which involves the same type of variation of the anomalous charging current, and an entirely analogous method of assuming a number of terms and of studying their grouping. It appears certain that an equally good agreement would have been obtained from Wagner's equations. In fact, it is safe to say the same of any theory providing for the medium a sufficient number of terms, all obeying a continually decreasing function $\varphi(t)$ of relatively simple form, but with different values of the constant terms. It appears not improbable that Wagner, not caring for von Schweidler's idea of slow period molecular oscillations, set out to picture a structure of an anomalous dielectric which would involve only the fundamental properties of specific inductive capacity and conductivity, thus adhering to Maxwell's ideas.

Group 3. Theories Based on the Structure of the Atom

Decombe in seeking an explanation of the heating of condensers, notes the remarkable and very general fact, that most thermodynamic modifications are inseparable from noticeable electric phenomena. Thus, mechanical deformations are always accompanied by both heat and electrification, (tribo-, and piezo-electric effects); capillary deformations, shock, cleavage, etc., all result in both heat and electric manifestations. Similar effects are noticeable in chemical relations, as in the thermal variations of crystals, the thermo-electric cell, the Thomson and Peltier effects, etc. He, thus, concludes that dielectric absorption and losses are also to be explained in terms of motions or deformations of electrons within the atom, and he bases an interesting and extended development of this theory on the general electron theory of Lorenz:

Separating the displacement of the ether from that of the material, as in Maxwell's theory:

$$Q = \frac{E}{4\pi} + P \tag{25}$$

Q being the total charge, and P the "polarization." P, he assumes to be due to electron displacement and it therefore obeys Lorenz's equation:

$$E = a\frac{d^2 P}{d t^2} + b\dot{P} + c\frac{d P}{d t} \tag{26}$$

E being the electric intensity and a, b, and c constants of the reactionary forces of acceleration, elasticity, and friction respectively. He assumes further that for frequencies less than those of light the first term on the right is negligible, and so

$$E = b\,P + c\frac{d P}{d t} \tag{27}$$

He shows that (27) obeys the principle of superposition, and also that it is satisfied by a value of alternating polarization computed from oscillograms taken by Hochstadter on high-tension cables. He shows further that Maxwell's equations as extended by Hess, when applied to the alternating case reduce to the same form as his own, and so by inverse reasoning, account is made for residual charge. Moreover, he shows that Pellat's arbitrary expression for the variation of the displacement follows immediately from his own equations. He shows also that under alternating e. m. f. the equations lead to a loss proportional to the square of the polarization current $\left(\frac{d P}{d t}\right)$, and a loss per period independent of the frequency, as shown experimentally by Steinmetz, Hochstadter and others. The general conclusion is that all residual effects are due to the term $c\frac{d P}{d t}$, representing a frictional force (electric) within the atom, *i. e.*, to a viscous property of the atom.

The theory is very striking in its agreements with the results of observation and in its simplicity.

Group 4. Theories Based on Anomalous Conductivity

It has often been suggested that dielectric absorption is in fact due to a varying conductivity giving rise to the motion of movable charges of "ions" within the dielectric. Experimental investigations of this idea as applied to solids are very difficult, but the irreversible anomalous current of a poorly conducting liquid offers very much wider opportunity.

Efforts have been made also to extend the same explanation (*i. e.*, ionic conduction) to the anomalous charge and discharge currents of solids, but with little success. von Schweidler has maintained that in an ionized medium the reversible anomalous current can not arise. Also that the principle of superposition cannot be explained in this way, and offers as proof the absence of residual charge in liquid dielectrics. On the other hand, Anderson and Keane have shown that the drifting of free electrons to the positive electrode will result in a space variation of charge sufficient to account for residual charge in accordance with Maxwell's theory, and have checked their conclusions with observations on sulphur. The behavior of glass is especially significant in this connection. The final conductivity of glass has undoubtedly an electrolytic character. Sodium is deposited out of glass on the electrodes, with resulting decrease of conductivity, and the latter may be maintained by providing an anode of sodium amalgam. Lithium may also be used, but apparently no other metals of the chemical group. Moreover the electrolytic action is in accordance with Faraday's laws. It must be remembered, however, that glass is not a homogenous substance and in fact

is generally considered to be a solid solution, and so of highly special character. On the other hand similar behavior has been observed in quartz, certainly not a solution, but in which small quantities of sodium and lithium are usually present. Mercury, quartz, and sodium form an electrolytic cell giving about .5 volts. H. H. Poole has shown the relation $x = e^{a+b+X}$ for the conductivity of glass, a being the thickness and X the field intensity; *i. e.*, the conductivity increases with the field strength. Gunther-Schulze sees in this an evidence of ionic conductivity and ionization by collision as in gases. Thus, while we may not be sure that glass presents a behavior typical of all anomalous dielectrics, it unquestionably is significant as showing the possibility of ionic conductivity in solids.

The Influence of Moisture. Cable paper absorbs up to 10 per cent, or even 20 per cent, by weight of moisture, rapidly at first and then more slowly. Under continuous voltage when comparatively dry (2 per cent to 3 per cent moisture) it shows a typical absorption curve in accordance with formula (**3**) $i_1^1(t) = a\ t^{-m}$. With increasing moisture the ordinates increase, and the curve flattens out, becoming horizontal (except for a short initial descending portion) at about 7 per cent moisture. Above this the curve of charging current with time rises gradually (Lübben). These increases are all of the nature of conduction current, for the discharge current does not take on corresponding increases, and follows equation (**3**) in all cases. Thus, the difference between charge and discharge currents, which usually measures the insulation resistance, increases continually with time after the application of voltage (Wagner). This indicates that the continued application of voltage causes a decrease in resistance. Moreover, the final steady value of resistance is found to depend on the voltage. So that we have the following approximate relations for the resistance r, the conductance g, and the conduction current i, in a fibrous dielectric containing moisture:

$$r = \frac{A}{\sqrt{E}};\ g = g_0\,E^m;\ i = i_0\,t^p \qquad (\mathbf{28})$$

E, being the voltage and A, g_0, m, i_0, p constants.

An ingenious explanation of many of the above relations has been offered by Evershed who supposes that the water is in part contained in the capillary tubes of the fibers of the material. The water is separated by air bubbles, but the walls of the tube surrounding the bubbles are wet with a thin film of water. These films constitute the principle resistance of the complete water path. Under the electric field, water is forced from the drops in the films making their walls thicker and so increasing their conductivity. In the thin state of the films they are very sensitive to slight water addition, but less so as the walls get thicker, corresponding to the observations of experiment. Evershed constructed a model containing a large number of glass capillary tubes, and studied its behavior under the microscope. He found that it gave the typical resistance, voltage, time relations found for fibrous insulation, and that the water films behaved as already stated.

D. DuBois has suggested a somewhat different mechanism for the behavior of water in dielectrics.

J. Curie showed the important part water may play in materials containing no fibers but which are porous. By maintaining porcelain at different degrees of moisture he reproduced different types of charging current curve, among them typical absorption curves as observed for dry substances. Moreover, this moist porcelain polarized up to several hundred volts, gave typical discharge curves and in fact obeyed the principle of superposition. Curie suggests in explanation the linking up of a number of internal individual electrolytic cells due to water and local conducting impurities.

V. Dielectric Behavior under Alternating Electric Force

The alternating losses in condensers were first noted by Siemens (1864), and since then they have been studied by many observers.

For a long time and even up to the present, many have assumed that the cause of these losses is to be found in some special and unknown property of dielectrics, usually called dielectric hysteresis and supposedly arising in some undiscovered molecular phenomenon, similar to that in magnetic materials. It is remarkable that this illusion should have maintained so persistent a hold, for it is easy to see that the phenomenon of absorption causes a lag of charge behind e. m. f. and so is sufficient to account for the energy component of current.

Theories Based on Absorption. Beaulard in 1894 and *Hess*, in 1895, gave convincing arguments against the idea of hysteresis, and *Hopkinson*, in 1897, made alternating measurements, attempting to link up absorption with the values of capacity and loss currents.

Rowland extended Maxwell's theory of absorption to the case of a sinusoidal e. m. f. and derived expressions, showing variations with the frequency, of both the capacity and the phase difference. He developed a sensitive electrodynamometer, many special types of bridge connection, and with his coworkers made numerous studies of dielectric loss, failing, however, to find close agreement with the Maxwell theory. The measurements of Curtis, in 1910, also failed to agree with this theory.

von Schweidler. Grover, in 1911, made a similar effort not only with the Maxwell-Rowland expressions, but also by extending the theories of Houllevigue, Pellat, von Schweidler, and Hopkinson, to the alternating case, and checking them with measurements on a number of condensers for frequencies up to 1000 cycles, and temperatures between 10 deg. and 35 deg. He found that von Schweidler's extension of Pellat's theory was the only one which could be made to give

quantitative results in agreement with the observations.

Wagner. Wagner has also extended his picture of the Maxwell dielectric to the alternating case in a series of papers dating from 1913. He assumes the simplest possible case of a two-layer Maxwell dielectric, and further that the conduction and displacement currents flow simultaneously, that the total currents are equal in each dielectric, and that the alternating electromotive force on the condenser is the vector sum of the e. m. f's. on the two layers. This leads at once to a complex expression for the impedance of the condenser, from which the following values of the variable dielectric constant (and so the capacity) and the variable angle of phase difference at once appear:

$$K\,\omega = K\left[1 + \frac{k}{1 + \omega^2 T^2}\right] \qquad (30)$$

$$\tan\delta = k\,\frac{\omega T}{1 + K + \omega^2 T^2} \qquad (31)$$

in which K is the specific inductive capacity corresponding to the geometric capacity, T the time constant in the exponential expression of the anomalous charging current, k a simple function of the electric constants of the two materials, and $\omega = 2\pi f$.

These two equations are in some degree in qualitative accord with the results of experiment. The former (**30**) indicates a capacity starting at a finite value and decreasing with the frequency to the geometric value at infinite frequency. This behavior is universally found in experiment. The latter equation (**31**) indicates a phase difference starting at zero, at 0 frequency, and with increasing frequency passing through a maximum and then steadily decreasing toward zero at infinite frequency. This general behavior has also been frequently observed. At times the maximum value of $\tan\delta$ may not appear, the frequency at which it occurs being determined by the constant k, and often lying outside the available range. On the other hand many other observations do not follow the comparatively simple relations indicated by (**30**) and (**31**).

Decombe has extended his electron theory of the anomalous behavior of dielectrics, already described in connection with absorption, to the explanation of alternating losses.

F. Tank has studied the Pellat-Schweidler theory for the alternating case, computing the loss as due to absorption, measuring the latter and also measuring the loss, and comparing with the computed value. The method used for computation is typical in the main of the methods used by several others (Wagner, Lahoussé) and is briefly as follows: The alternating current due to an e. m. f. $E = E_0 \sin\omega t$, flowing in a condenser circuit may be expressed

$$i = (t) = a\sin\omega t + b\cos\omega t; \qquad (33)$$

further by the principle of superposition, see formula (**10**), the anomalous charging current is:

$$i\,(t) = \beta\,C\int_{-\infty}^{t}\left(\frac{d\,E\,(u)}{d\,u}\right)\varphi\,(t - u)\,d\,u \qquad (34)$$

t being the instant at which the current is considered, and u the elapsed time since the application of E. Equating the two values of $i\,(t)$, the coefficients a and b may be obtained thus showing the influence of absorption on both the capacity and the apparent conductance of the condenser.

Tank found a remarkable agreement between the measured and computed losses and currents, the per cent differences for the former in the six cases being 3.8, 4.1, – 0.4, 1.6, 13.8 and 23 per cent. He concludes from his work that the alternating losses in solid dielectrics are almost entirely accounted for by absorption, resistance loss being less than 1 per cent of the total, and no evidence of other losses.

Lahousse adopts a slightly different method of approach for computing the loss from the absorption. If E is the electric intensity, I the polarization, and k the dielectric susceptibility ($K = 1 + 4\pi k$),

$$I = k\,E\,(t) + \int_{-\infty}^{t} k\left(\frac{d}{d\,u}\,E\,(u)\right)\varphi\,(t - u)\,d\,u \qquad (35)$$

For a closed cycle, the loss per cycle, w, is:

$$= \int E\,d\,I = -\int I\,d\,E \qquad (36)$$

Substituting $E = E_0 \sin\omega t$, and introducing two new constants a and β whose values are determined by the integral in (**35**);

$$I = K\,E_0\,[\sin\omega t + a\sin(\omega t - \beta)] \qquad (37)$$

This is the equation of an ellipse between I and E_0, a result independent of the form of $\varphi\,(t)$. Such ellipses have been shown experimentally by Granier. (See below).

Further, from (**36**) and (**37**)

$$w = \pi\,k\,a\,E_0^2 \sin\beta \qquad (38)$$

or the loss is proportional to the square of the applied e. m. f. as often observed. Both the foregoing relations are independent of the form of $\varphi\,(t)$, which is contained in β. If $\varphi\,(t) = m\,e^{-nt}$ (Maxwell, Curie, et al), and if n is small as usually observed, the loss per cycle becomes

$$W = \frac{2\,k\,\omega\,m\,E_0^2}{\omega^2 + n^2} = \frac{2\,k\,m\,E_0^2}{\omega} \qquad (39)$$

and the total loss

$$W = \frac{k\,m\,E_0^2}{\pi} \qquad (40)$$

that is the loss per cycle is inversely proportional to the frequency, and the total loss independent of the frequency. As indicated below, these relations have some apparent support, but the weight of the evidence of experiment shows a loss increasing with the frequency.

J. Granier has investigated in very elegant manner the losses due to absorption alone for alternating frequencies between 0.3 and 150 cycles. He interrupts

the steady alternating excitation at different points on the cycle, and by a careful zero method obtains the total residual charge. This permits the plotting of the absorption-voltage relation for a complete cycle at each frequency. Plotted in rectangular coordinates the curves are found to be almost perfect ellipses, as called for by theoretical analysis (c. f. Lahousse above). The areas of the ellipses, representing the loss per cycle, continually decrease with increasing frequency, also in general accord with theory. The ellipses become quite flat within the range mentioned, and the study of the influence of frequency is continued up to 1500 cycles, using bridge methods. Within the entire range the total loss increases, but less than in proportion to the frequency.

VI. Comparison of Alternating Theory and Experiment

Loss-Voltage. There is almost universal theoretical agreement that the rate of loss varies as the square of the electric intensity. Many observers have studied this relation (see bibliography), and the extreme range of the exponent of the electric force appears to be from 1.3 to 2.7. However, the great mass of the evidence centers about the value 2. It is difficult to account for the values lying below 2, but those lying above permit of quite probable explanation.

Loss-Frequency. In the matter of frequency the several theoretical developments are not in entire accord. Wagner shows the loss proportional to both frequency and phase difference and as the latter first increases and then decreases with the frequency, a uniform variation in the loss is not always to be expected. Lahousse deduces a loss per cycle inversely proportional to the frequency and thus a loss per second independent of the frequency, for all but very low values. The experiments of Granier show a loss per cycle decreasing with the frequency up to 150 cycles, and a loss per second increasing only as the 0.5th and 0.6th power of the frequency, thus seeming to lend some force to Lahousse's conclusion. M. A. Frigon reports the losses in impregnated paper increasing nearly in proportion to the frequency between 20 and 60 cycles. H. J. MacLeod working on such good insulators as glass, pyrex, paraffin, cresin, mica, and with unusually careful conditions finds the losses varying as the 0.85th to 0.9th power of the frequency. Many other observers have reported losses increasing with the frequency but usually in less than direct proportion.

On the other hand, Wagner has examined the variation of the power factor with frequency over a wide range, and finds that the maximum value of the phase difference may occur for different substances in the range of 4 to 1000 cycles per second, and higher. This means that within the commercial range and far beyond, the phase difference may either increase or decrease with the frequency. This is probably the chief cause of the general confusion to be found in attempting to coordinate the results of different observers, and the reason why no simple empirical law has appeared expressing the influence of frequency on dielectric loss.

Loss-Temperature. The influence of temperature on dielectric loss is very great, the loss rapidly increasing with the temperature. But here too, it does not appear possible to expect a definite law owing to the indirect influence of temperature on other properties.

The only considerable attempt to account for the influence of temperature from a theoretical standpoint is that of Wagner. He carries it back to its effect on the time constant of the material, *i. e.*, the factor multiplying t, the time, in the exponential variation of the anomalous charging current. This enables him to bring it through into the alternating case, in its effect on phase difference, and so on the loss. He reports some remarkable general agreements with the results of observation, and his work stands out as a striking support, in the matter of temperature, of Maxwell's theory.

VII. Summary and Conclusions

1. Dielectric absorption is a conspicuous but obscure and little understood phenomenon. Its general character is well known as shown by the decay, with time, of the charging current, residual charge, etc. However, exact and definite forms of even the empirical laws are still lacking.

2. Only solids show the complete absorption phenomena of charge and discharge. Liquids often show an apparent absorption in charging but no residual phenomena. Nearly all solid dielectrics show some absorption. In some substances in a very pure state, *e. g.*, sulphur, quartz, paraffin, it is very small, if not negligible, in amount.

3. Large changes in the absorption in solids may be caused by extremely small changes in composition. Impurities and moisture in very small amounts may cause large changes in absorption.

4. The charging absorption current merges into a final steady conduction current. Both are strongly increased by increase in temperature, the absorption finally disappearing or changing into conduction.

5. The alternating losses in solid dielectrics are due almost entirely to absorption. This is shown by theoretical analysis, and confirmed by experiment. The losses due to conductivity are usually very small compared with those due to absorption, and there is no evidence of losses of other types. There is nothing to indicate a hysteresis loss of the character pertaining to magnetic materials.

6. Theories of the ultimate nature of the phenomenon of absorption are: (*a*) That it arises in the mixture of two or more dielectrics, and depends only on the known quantities, conductivity and specific inductive capacity. This is the theory of Maxwell. (*b*) That it is due to anomalous relation between electric dis-

placement and electric force, the seat of which is within the molecule or atom. Pellat, (*c*) That it may be explained by Lorenz's theory of electron motion within the structure of the atom. Décombe. (*d*) That it is due to water in capillaries or interstices in the body of the dielectric.

7. The most satisfactory theory is that of Maxwell though it is far from firmly established. The evidence is mostly indirect and it still needs quantitative proof. Probably its firmest support is found in the extension to the alternating case in which it explains a number of experimental observations. However, the theories of class (*b*) are susceptible to much the same extension.

8. From the standpoints of both theory and practise there is great need and fine opportunity for further study of the phenomenon of absorption. Thoroughgoing and careful efforts to test Maxwell's theory have been remarkably few in number. It should not be difficult to plan a comprehensive series of experiments for that purpose. Much the same may be said as to the question of the presence of electrolytic conduction in dielectrics, and its importance as a factor in explaining absorption. Moisture is difficult to eliminate completely from many dielectrics. It influences profoundly the permanent conductivity, and probably the absorption. Whether or not it is a definite factor in all absorption is a question needing, and apparently susceptible of experimental solution.

The complete paper includes an extensive bibliography on the subject of Dielectric Absorption.

Compensation for Errors of the Quadrant Electrometer in the Measurement of Power Factor

BY D. M. SIMONS[1] and WM. S. BROWN[1]
Associate, A. I. E. E. Associate, A. I. E. E.

Synopsis;—*In a previous paper, the writers developed the equations for the main errors in the quadrant electrometer for the measurement of power factor, and checked their equations experimentally, the main sources of error being the unavoidable shunting capacity to ground of the test specimens and the charging current from the electrometer needle to the quadrants. In the present paper methods of experimental compensations and elimination of these sources of error are described. Methods of compensation for capacity to ground have been presented before, and in this paper merely some additional refinements are given. The method of compensation for errors due to the charging current in the needle circuit is believed to be new; the method is described herein, the equation is derived in full, and an experimental check is given of the accuracy of the equation.*

* * * * *

I. Introduction

In a previous paper[2], the general equations of the electrometer have been given, both for the ordinary deflection method and for a new null method where the deflection is brought back to zero by inserting resistance in series with the electrometer needle. In order to save space, the previous work will not be described here, but the compensation for errors will be covered, practically as a continuation of the previous article. The following symbols will be used.

E = Voltage on the load taken as numerically equal to the transformer voltage

I = Load current or charging current of the specimen

I_h = Charging current flowing from the needle to the high quadrant

I_l = Charging current flowing from the needle to the low quadrant

r_1 = Resistance across the electrometer quadrants

r_2 = Resistance inserted in the needle circuit in the zero method, *i. e.*, the potential resistance

C_1 = Total capacity to ground of the high quadrant and all connected parts

C_2 = Capacity in the needle circuit

$\cos \phi$ = Power factor of the load

$\cos \psi$ = Power factor of the circuit in which I_h flows

n = Ratio of the transformer voltage to the needle voltage

f = Frequency

ω = $2 \pi f$

In the former paper it was shown that the main source of error was due to the capacity to ground of the "high quadrant" and all connected parts, including the capacity to ground of the high quadrant itself, all connected leads, the distributed capacity of the quadrant resistance, and the capacity to ground of the low-voltage electrode of the test specimen, the last usually being a large percentage of the total. Stated differently, a large part of the reading, either by the deflection or null method, is due to the capacity to ground. It was further shown that errors would be introduced by the charging current from the needle to the high quadrant, if the load current is so small that the needle current is no longer comparatively negligible.

In the previous paper, equations were given to include

1. Both of the Standard Underground Cable Co., Pittsburgh, Pa.

2. *The Quadrant Electrometer for the Measurement of Dielectric Loss*, D. M. Simons and W. S. Brown, Trans. A. I. E. E., 1924, p. 311.

Presented at the Regional Meeting of District No. 1 of the A. I. E. E., Niagara Falls, N. Y., May 26-28, 1926.

the effect of these two sources of error as well as others. In the present paper it is proposed to give methods of experimentally compensating for these two errors, so that these terms will disappear from the general equation, and so that the final reading may be taken as if these errors did not exist. This also means a great increase in accuracy, since in general the power factor of the unknown will constitute a large part of the reading, if compensation is made. Without compensation, the power factor of the unknown load may be a very small part of the total reading, and therefore any errors may have a disproportionately great effect upon the accuracy of the power factor measured.

II. Neutralization of Capacity to Ground, C_1

Considerable errors may develop in the measurement of power factor if a large part of the reading is due to capacity to ground, C_1. For that reason, there is often a real necessity for compensating for the greater portion, if not all, of the capacity to ground. This can be done in large part by raising the potential of the shield surrounding the low-voltage electrode of the test specimen to the same potential as that of the electrode itself. For example, in the measurement of small specimens of cable, the sheath must be surrounded by a grounded shield in order to avoid stray currents. If this shield is insulated and raised to the potential of the sheath, the capacity to ground of the sheath will be ineffective.

If desired, compensation may be even more perfect than that. If the quadrants consist of tinfoil pasted on glass, other sheets of tinfoil of the same size could be pasted on the other side of each piece of glass opposite the high quadrants and insulated from the instrument. All leads to the high quadrant are normally surrounded by grounded guards, which for this purpose should be insulated. The guards of the quadrants and of the leads may now be connected to the shield surrounding the low-voltage electrode of the test specimen, and all raised to the potential of this electrode. This will compensate for all capacity to ground except the distributed capacity to ground of the quadrant resistance which is normally very small. When n equals 2, under these conditions practically all of the reading will be due to the power factor of the load.

Some experiments in compensation were performed where the load used was a short piece of cable. Fig. 1 gives the diagram of connections. The conductor of a similar piece of cable was connected to the high voltage and its sheath grounded through a resistance whose value was such that the potential drop across it was the same as that across the quadrant resistance. The sheaths of both specimens were therefore at the same potential. Compensation was then accomplished by connecting the sheath of the auxiliary specimen to the guard surrounding the load specimen.

The accuracy of compensation can be checked by a method suggested by R. W. Atkinson. A key and condenser in series are inserted between the sheath of the auxiliary specimen and the guard surrounding the load specimen. A rough adjustment of the resistance in series with the auxiliary specimen is then made and a balance or deflection taken. If compensation is correct, no change in the balance or deflection will result on closing the key. If any change does occur, the resistance in series with the auxiliary specimen can be adjusted until the reading is independent of the position of the key. If a key were used without the series condenser, the balance would probably be too sensitive, due to possible differences in power factor of the load and auxiliary specimen.

Compensation for capacity to ground may be very advantageously applied to the method outlined in Section 5 of the former paper, where two balances are required, one on a zero-loss standard S and one on the unknown X, the total capacity to ground being kept constant. This can be accomplished in the following

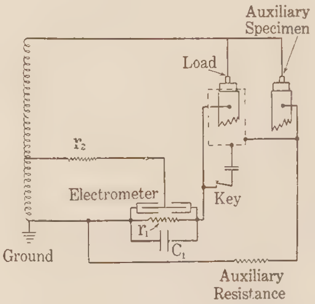


Fig. 1—Diagram of Connections for Compensation for Capacity to Ground in Quadrant Electrometer

way. Insulate the guards of both S and X and connect them to the low-voltage electrode of the auxiliary specimen. Connect S to the high voltage, and the high-voltage lead of X to the low-voltage electrode of the auxiliary specimen. Balance on S, compensation being made by means of the auxiliary resistance, series condenser and key. Then connect X to high voltage, connecting the high-voltage electrode of S to the low-voltage electrode of the auxiliary specimen. Balance on X, compensating again. A different value of auxiliary resistance, of course, will be required if the charging currents of X and S are not the same. The difference between the two $r_2 C_2 \omega$'s will give the power factor of X. The great advantage of this method lies in the fact that the capacity to ground of the instrument and leads does not have to be compensated for, and the difficulty of the shunting capacities, C_a and C_b is entirely eliminated.

III. Neutralization of the Needle Charging Current, I_h

The method used to neutralize the effect of I_h is shown in the diagram of connections, Fig. 2. The essential difference between this and the ordinary connection is that a graduated variable condenser C_3 and a variable resistance r_3, are inserted in parallel between

the low quadrant and ground. The procedure follows:

1. Connect the low-voltage electrode of the test specimen to the high quadrant, leaving the high-voltage electrode floating, a convenient quadrant resistance r_1 being inserted as usual. An equal resistance, r_3 is then inserted between the low quadrant and ground and sufficient capacity C_3 is cut in until the instrument reads zero.

2. Apply high voltage to the specimen. Inasmuch as during the previous balance the total capacity to ground of the high quadrant was higher by C_{ab} (see Section 6 of first paper), this amount of capacity must be deducted from C_3. The deflection is now brought back to zero by the potential resistance r_2 as usual (or a deflection taken), and the power factor may be obtained by the following formula:

$$\cos\phi + r_1 C_1 \omega - \frac{n-2}{2} \cdot \frac{I r_1}{E} + r_1 C_q \omega + \frac{I_h r_1}{E} = r_2 C_2 \omega \qquad (1)$$

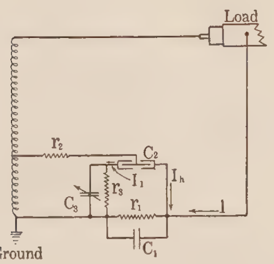


Fig. 2—Diagram of Connections for Neutralization of I_h

in which C_q *is the capacity between the high and low quadrants themselves,* and C_1 is as usual the capacity to ground of the high quadrant and all connected parts, when the low quadrant is grounded. C_1, therefore, includes C_q. C_q is in most cases absolutely negligible, especially if the quadrants are made of tinfoil on glass, and the last term on the left is usually negligible. It will therefore be seen that equation (**1**) is practically identical with equation (**6**) of Part II of the previous paper, and that all effects of the charging current I_h have been neutralized. Furthermore, the equation is entirely independent of the load current if n equals 2, and therefore, if the compensation is made, the method of balancing first on a standard condenser and then on an unknown condenser could be made regardless of the relative sizes of the two condensers, except as influenced by the changes in capacity to ground as explained in the previous paper.

Another obvious method of avoiding the effects of I_h might be briefly mentioned. If the charging current to the high quadrant is approximately equal to that of the low quadrant, and the losses are the same on both sides, all effects due to them should be removed if the ground were placed at the midpoint of the quadrant resistance, instead of grounding one set of quadrants. We believe that there is one great difficulty with this method. The low-voltage terminal of the test transformer would, of course, have to be insulated. All stray currents therefore from the high-voltage end of the transformer to ground would return to the low-voltage terminal of the transformer through the ground connection and therefore through the lower half of the quadrant resistance, thereby introducing an indeterminate and, possibly, large correction.

IV. Derivation of Equation for Neutralization of I_h

In the previous paper, an analytic method using the symbolic notation has been used. As stated in each case, the equations have also been derived geometrically from the vector diagrams with a perfect check. It appears that the present derivation is considerably simpler by the geometric method. At first thought, some of the geometry may appear too free, but it is believed to be justified because the actual vector diagram, if drawn to scale for a high-voltage measurement, especially with n equal to 1 or 2, would be so elongated that, for instance, all the vectors from the needle potential points, R, T, etc., to either quadrant are practically identical in absolute value. It is believed that practically all the substitutions about to be made are equivalent to the assumption that the angles are all so large or small that their sines or cosines, as the case may be, are equal to unity. An additional reason for confidence is that practically this same process and same assumptions completely checked the other equations derived analytically after the assumption that certain sines and cosines were equal to unity.

The vector diagram is shown in Fig. 3. $A\,B$ is the transformer voltage. $A\,N$ is the load voltage, the load current being the vector of reference. Angle $X\,A\,N$ = angle $A\,N\,M$ = cos ψ, the load power factor. B is the grounded point. The potential resistance, r_2 in Figs. 1 and 2 is connected to the transformer at any point, T.

In these first two figures r_1 and C_1 are as usual the quadrant resistance and the unavoidable shunting capacity and r_2 and C_2 are as usual in the potential circuit. It will be assumed that a resistance r_3, shunted by a capacity C_3, has been inserted between the "low quadrant" (the one usually grounded) and ground, no assumptions being made as to their present values. Let I_h and I_l be the charging currents from the needle to both the high and low quadrant respectively, and let cos ψ and cos ψ' be the power factors of these two currents respectively, as referred to the voltage between needle and quadrant.

Returning to Fig. 3, $N\,J'$ is the resultant voltage across the quadrants to be mentioned later. O is the midpoint of the transformer high-voltage winding, and T is the point at E/n to which r_2 is connected. $T\,R$ is the voltage drop across r_2, and $R\,D$, perpendicular to it is the effective needle voltage—assuming that

C_2 is the capacity of the instrument itself, though actually an auxiliary potential condenser is used as explained in Section 3 of the earlier paper.

If there were no capacity to ground from the high quadrant and connected parts ($C_1 = 0$) the drop across the quadrant resistance r_1 due to the load current I would be in the direction $N\,I$, parallel to $A\,X$. Due to the capacity C_1, the drop lags by an angle α and may be represented by $N\,J$. $R\,N$ is the voltage between the needle and the high quadrant, angle ψ being angle $R\,N\,H$. The direction of I_h is therefore $N\,L$, $H\,N\,L$ being a straight line. The drop across the quadrants due to I_h lags behind this by the same angle α, and therefore the drop due to this current is $N\,E$. Sup-

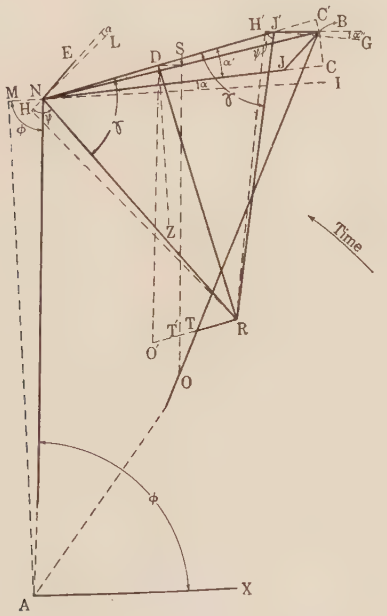


FIG. 3—VECTOR DIAGRAM FOR THE NEUTRALIZATION OF I_h

posing r_3 and C_3 to still be zero, the drop across the quadrants is $N\,B$, the vector sum of $N\,J$ and $N\,E$. If resistance and capacity are now added between the low quadrant and ground, namely r_3 and C_3, the diagram changes. $R\,J'$ is the voltage between the needle and low quadrant, angle $R\,J'\,H'$ is angle ψ', and $J'\,G$ is the direction of I_l the charging current to the low quadrant. The drop across the resistance r_3 due to I_l lags behind this by an angle α'' (not equal to α, unless $r_1 = r_3$, and $C_1 = C_3$). The total quadrant voltage due to I and I_h in r_1, and I_l in r_3 is the resultant of $N\,B$ and $B\,J'$, or is equal to $N\,J'$ as stated above, making the angle α' with $N\,J$.

The condition of zero deflection of the instrument is that the voltage across the quadrants shall be perpendicular to the voltage from the needle to the midpoint of the quadrants, *i. e.*, $R\,D$ is the perpendicular bisector of $N\,J'$, and the proof centers about the triangle $O'\,D\,R$, including the condition mentioned above and the fact that $O'\,R$ is perpendicular to $R\,D$.

Take S as the midpoint of $N\,B$, and draw $D\,S$, which will equal one-half of $J'\,B$. Draw $O\,S$, cutting $T\,R$ produced in T'. Draw $D\,O'$ parallel to $O\,S$.

$$O\,B = E/2$$
$$T\,B = E/n$$

Therefore,

$$O\,T = O\,B - T\,B = \frac{n-2}{2\,n}\,E$$

Therefore,

$$\frac{O\,T}{O\,B} = \frac{n-2}{n} = \frac{T'\,T}{S\,B}$$

Now,

$$S\,B = N\,B/2 = \frac{(I + I_h)\,r_1}{2} \text{ (if } \cos B\,J\,C \text{ and } \cos$$

$B\,N\,C$ are taken as unity)

Therefore,

$$T'\,T = \frac{n-2}{n} \cdot \frac{(I + I_h)\,r_1}{2} \qquad (2)$$

Now,

$T\,R = r_2$ times current in potential circuit

$$= \frac{E\,r_2\,C_2\,\omega}{n} \qquad (3)$$

(Since the potential voltage T to D may be confused with $T\,B$ or E/n in scalar value)

Now,

$$O'\,T' = D\,S = J'\,B/2 = \frac{I_l\,r_3}{2} \qquad (4)$$

($O'\,D$ and $O\,S$ are parallel by construction, and in the actual diagram $D\,S$ and $O'\,T'$ are practically parallel)

$$\text{Angle } O'\,D\,R = 90 \text{ deg.} - \phi + \alpha + \alpha' \qquad (5)$$

(This may be seen by drawing a line $D\,Z$ from D perpendicular to $N\,I$. $O\,S$ is parallel to $A\,N$ because O and S are the midpoints of $A\,B$ and $N\,B$ by construction, and $D\,O'$, drawn parallel to $O\,S$, is also parallel to $A\,N$. Angle $O'\,D\,Z$, therefore, $= 90$ deg. $- \phi$. $D\,R$ is perpendicular to $N\,J'$, and $D\,Z$ to $N\,I$ by construction. Therefore, angle $Z\,D\,R = \alpha + \alpha'$).

$$\text{Sin } O'\,D\,R = \frac{O'\,R}{O'\,D} = \frac{O'\,T' + T'\,T + T\,R}{E/n} \qquad (6)$$

Substituting, (2), (3), (4), and (5) in (6), we obtain

$$\sin\,(90 - \phi + \alpha + \alpha') = \cos\phi + \sin\alpha + \sin\alpha'$$

$$= \frac{n\,I_l\,r_3}{2\,E} + \frac{n-2}{2} \cdot \frac{(I + I_h)\,r_1'}{E} + r_2\,C_2\,\omega \quad (7)$$

$\sin\alpha = r_1\,C_1\,\omega$, and therefore only $\sin\alpha'$ remains to be determined.

An auxiliary angle γ will be introduced. $\gamma =$ angle $R\,N\,J' =$ angle $N\,J'\,R$.

$$\sin\alpha' = \frac{CC'}{N\,C'} = \frac{C\,B + B\,C'}{N\,B} \quad (N\,B = N\,C' \text{ if } \cos$$

$B\,N\,C'$ is unity and $C'\,B\,C$ is practically a straight line)

$$= \frac{J\,B \sin C\,J\,B + J'\,B \sin C'\,J'\,B}{N\,B}$$

But $N\,B = (I + I_h)\,r_1$, $J\,B = I_h\,r_1$, and $J'\,B = I_l\,r_3$
Angle $C\,J\,B =$ angle $C\,N\,E = 180$ deg.$- \psi - \gamma + \alpha + \alpha'$
Angle $C'\,J'\,B$ = angle $R\,J'\,C'$ − angle $R\,J'\,B$ = $(180 - \psi' + a'') = \psi' - \gamma - \alpha''$
Therefore,
sin α' =

$$\frac{I_h\,r_1 \sin(180 - \psi - \gamma + \alpha + \alpha') + I_l\,r_3 \sin(\psi' - \gamma - \alpha'')}{(I + I_h)\,r_1} \quad (8)$$

Simplifying, dropping the sines of large angles and cosines of small ones, and rearranging terms, we obtain:

$$\sin \alpha' = \frac{I_h}{I} \cos \psi + \frac{I_h\,r_1 + I_l\,r_3}{I\,r_1} \cos \gamma$$

$$+ \frac{I_h}{I} \sin \alpha - \frac{I_l\,r_3}{I\,r_1} \cos \psi' - \frac{I_l\,r_3}{I\,r_1} \sin \alpha'' \quad (9)$$

Since ψ and ψ' are circuit constants, and $\sin \alpha = r_1\,C_1\,\omega$, and $\sin \alpha'' = r_3\,C_3\,\omega$, the only unknown is the auxiliary angle γ, which must be evaluated.

From the figure,

$$\cos \gamma = \frac{N\,D}{R\,N} = \frac{(I\,r_1 + I_h\,r_1 - I_l\,r_3)/2}{E/n} \quad (10)$$

Substituting (**10**) in (**9**), and (**9**) in (**7**) and algebraically simplifying:

$$\cos \phi + \left(1 + \frac{I_h}{I}\right) r_1\,C_1\,\omega + \frac{I_h}{I} \cos \psi$$

$$- \frac{n-2}{2} \cdot \frac{(I + I_h) r_1}{E} = r_2\,C_2\,\omega + \frac{I_l\,r_3}{I\,r_1} \cos \psi'$$

$$+ \frac{I_l\,r_3}{I\,r_1}\,r_3\,C_3\,\omega - \frac{n\,(I\,I_h\,r_1^2 + I_h^2\,r_1^2 - I_l^2\,r_3^2)}{2\,E\,I\,r_1} \quad (11)$$

This is the general equation for $\cos \phi$ in terms of the circuit constants including a resistance and capacity between the low quadrant and ground, no assumptions having been made as to their relative values.

In the actual process of neutralizing the charging current I_h as described in Section 3 of this paper, the first step was to insert r_3 between low quadrant and ground, making $r_3 = r_1$. Thus r_3 is then shunted by C_3 until the electrometer reads zero, the high-voltage electrode of the load not being connected. This means that the electrometer is measuring two equal loads, one through each set of quadrants at full voltage E/n on the needle. The losses measured on each side must, therefore, be equal. Therefore, from equation (3) of the previous article:

$$\frac{E}{n}\,I_h \cos \psi + \frac{E}{n}\,I_h\,r_1\,C_1\,\omega + \frac{I_h^2\,r_1}{2}$$

$$= \frac{E}{n}\,I_l \cos \psi' + \frac{E}{n}\,I_l\,r_1\,C_3\,\omega + \frac{I_l^2\,r_1}{2} \quad (12)$$

Dividing by $E\,I/n$:

$$\frac{I_h}{I} \cos \psi + \frac{I_h}{I}\,r_1\,C_1\,\omega$$

$$= \frac{I_l}{I} \cos \psi' + \frac{I_l}{I}\,r_1\,C_3\,\omega + \frac{n(I_l^2 - I_h^2)r_1}{2\,E\,I} \quad (13)$$

And, since $r_3 = r_1$, (**11**) reduces to:

$$\cos \phi + r_1\,C_1\,\omega + \frac{I_h}{I} \cos \psi + \frac{I_h}{I}\,r_1\,C_1\,\omega$$

$$- \frac{n-2}{2} \cdot \frac{(I + I_h)\,r_1}{E} = r_2\,C_2\,\omega + \frac{I_l}{I} \cos \psi'$$

$$+ \frac{I_l}{I}\,r_1\,C_3\,\omega - \frac{n\,r_1\,(I\,I_h + I_h^2 - I_l^2)}{2\,E\,I} \quad (14)$$

If (**13**) be subtracted from (**14**), the equation reduces to equation (6) of the other article, except for a practically negligible term $I_h\,r_1/E$.

If this were so, our object would be accomplished, inasmuch as all terms containing the charging currents from the needle and the power factor of these currents would be removed. It was tried out experimentally on a known load and *did not check.* Finally, the error in reasoning was discovered. It has been assumed that C_1 and C_3 are the same in equations (**13**) and (**14**) respectively and also that C_1 is as usual the total capacity to ground of the needle and all connected parts. This is true *if the capacity between the quadrants themselves is negligible,* and only in that case. If this capacity, which is an essential part of the total capacity to ground, in the usual connection, is not negligible, then raising the potential of the low quadrant will diminish the capacity to ground of the high quadrant by a certain fraction of the capacity between quadrants, which will be called C_q. The fraction of C_q which will be taken away is inversely proportional to the potential of the quadrants, or since equal resistances r_1 and r_2 are used, inversely proportional to the currents flowing in these resistances.

We will, therefore, define C_1 as the total capacity between high quadrant and ground, when the low quadrant is grounded, and C_3 as the total capacity between low quadrant and ground, when the high quadrant is grounded. C_1 will therefore be the same as in all our other equations. The values of C_1 and C_3 given in the equations of this appendix are, therefore, different from this definition as explained above, inasmuch as they are capacities when equilibrium is reached.

Equations (**13**) and (**14**), as shown below, must, therefore, be rewritten and obtain equations in which these capacities agree with their definition in the beginning of this paragraph.

(**13**) becomes

$$\frac{I_h}{I}\cos\psi + \frac{I_h}{I} r_1 \left(C_1 - \frac{I_l}{I_h} C_q \right) \omega + \frac{I_h^2 r_1}{2}$$
$$= \frac{I_l}{I}\cos\psi' + \frac{I_l}{I} r_1 \left(C_3 - \frac{I_h}{I_l} C_q \right) \omega + \frac{n\,(I_l^2 - I_h^2)}{2\,E\,I} \qquad (\mathbf{15})$$

(**14**) becomes

$$\cos\phi + \frac{I_h}{I}\cos\psi + \left(1 + \frac{I_h}{I}\right) r_1 \left(C_1 - \frac{I_l}{I + I_h} C_q \right)\omega$$
$$-\frac{n-2}{2} \cdot \frac{(I + I_h) r_1}{E} = r_2\,C_2\,\omega + \frac{I_l}{I}\cos\psi'$$
$$+ \frac{I_l}{I} r_1 \left(C_3 - \frac{I + I_h}{I_l} C_q \right)\omega - \frac{n\,r_1\,(I\,I_h + I_h^2 - I_l^2)}{2\,E\,I} \qquad (\mathbf{16})$$

If (**15**) be subtracted from (**16**) the following is obtained

$$\cos\phi + r_1\,C_1\,\omega - \frac{n-2}{2} \cdot \frac{I\,r_1}{E} + r_1\,C_q\,\omega + \frac{I_h\,r_1}{E} = r_2\,C_2\,\omega \qquad (\mathbf{17})$$

This is the same as equation (**6**) of the former paper with the exception of the fourth and fifth terms, which in most instruments would be negligible, and therefore the effect of I_h has been practically neutralized by our method.

V. Experimental Proof of Neutralization of I_h

As mentioned in Section 4, it was thought at first that the method of neutralizing the effect of I_h outlined in Section 3 was practically perfect. It was tried out experimentally, a balance first being obtained on air condenser No. 1 in the usual manner, and then a balance was obtained after the procedure given in Section 3 was performed. It was expected that the balance after I_h had been neutralized would be smaller than before, primarily due to the elimination of the term $\frac{I_h}{I} r_1\,C_1\,\omega$. Instead of that, however, the potential resistance required after the neutralization process had been performed was *larger*, which was puzzling. The effect of the capacity between the quadrants themselves, namely C_q was then realized, and the derivation was changed as in Section 4. Finally equation (**1**) was obtained, including the effect of the capacity between quadrants. In our instrument, the quadrants instead of being tinfoil on glass, as is often the case, were cast aluminum plates, about 3/16 in. thick, with a beading along both the outside and inside and a rib at one point, which altogether made a by no means negligible area between adjacent quadrants, the separation between quadrants being about 1/16 in. C_q was calculated on the basis of 1/16 in. separation and the effective area between quadrants, and was also calculated from the balance described by means of equation (**1**), all other quantities being known. These two values of C_q checked to within about 10 per cent, which seems quite satisfactory, inasmuch as the actual capacity between quadrants could not be calculated accurately.

It was not convenient to measure this actual capacity and the easiest method of checking equation (**1**) was actually to shunt a known condenser between quadrants and measure its capacity by a series of readings, including our procedure for neutralizing I_h.

The four following readings were taken, at 14,000 volts with half voltage on the needle, 100,000-ohms quadrant resistance, r_1 and at 60 cycles.

1. Air condenser No. 2 alone with no compensation.
2. Air condenser No. 2 alone with I_h neutralized.
3. Air condenser No. 2 with an additional condenser of capacity C_A shunted across the quadrants, no compensation.
4. Air condenser No. 2 with the *additional* condenser C_A *across the quadrants*, I_h neutralized.

By "with I_h *neutralized*" in the readings 2 and 4 above, is meant that the process outlined in Section 3 was performed, namely that the low-voltage electrode of the load was connected to the high quadrant with the high-voltage electrode point floating. A resistance of 100,000 ohms was then inserted between the low quadrant and ground, and shunting this a variable capacity was connected, which was so adjusted that the reading of the electrometer was equal to zero. This variable condenser which was graduated and calibrated, was reduced in capacity by an amount equal to the C_{ab} capacity of the load, and the high voltage was then connected to the load, and a balance performed by means of the potential resistance as usual.

Following are the values of potential resistance used, and also $r_2\,C_2\,\omega$

Reading	r_2	$r_2\,C_2\,\omega$
1	18,570 ohms	0.02950
2	19,600 "	0.03113
3	25,100 "	0.03988
4	31,600 "	0.05020

Remembering that the power factor of air condenser No. 2 is zero, the two following equations, according to equation (**8**) of the other and equation (**1**) of this paper, are obtained from the readings 1 and 2 respectively.

$$0 + \frac{I_h}{I}\cos\psi + \left(1 + \frac{I_h}{I}\right) r_1\,C_1\,\omega$$
$$+ \left(1 + \frac{I_h}{I}\right)\frac{I_h\,r_1}{E} = 0.02950 \qquad (\mathbf{18})$$

$$0 + r_1 C_1 \omega + r_1 C_q \omega + \frac{I_h r_1}{E} = 0.03113 \qquad (19)$$

Remembering that during readings 3 and 4 the total capacity to ground, as defined is equal to $C_1 + C_A$, and that the total capacity between quadrants is $C_q + C_A$, the two following equations are derived from both the equations (8) and (1) and the readings 3 and 4.

$$0 + \frac{I_h}{I} \cos \psi + \left(1 + \frac{I_h}{I}\right) r_1 (C_1 + C_A) \omega$$

$$+ \left(1 + \frac{I_h}{I}\right) \frac{I_h r_1}{E} = 0.03988 \qquad (20)$$

$$0 + r_1(C_1 + C_A)\omega + r_1(C_q + C_A)\omega + \frac{I_h r_1}{E} = 0.05020 \qquad (21)$$

Subtracting equation (19) from equation (18):

$$\frac{I_h}{I} \cos \psi + \frac{I_h}{I} r_1 C_1 \omega + \frac{I_h}{I} \cdot \frac{I_h r_1}{I} - r_1 C_q \omega$$

$$= - 0.000163 \qquad (22)$$

Subtracting (21) from (20)

$$\frac{I_h}{I} \cos \psi + \frac{I_h}{I} r_1 (C_1 + C_A) \omega - r_1 (C_q + C_A) \omega$$

$$+ \frac{I_h}{I} \cdot \frac{I_h r_1}{E} = - 0.01032 \qquad (23)$$

Taking equation (23) from equation (22),

$$r_1 C_A \omega \left(1 - \frac{I_h}{I}\right) = 0.00969 \qquad (24)$$

Knowing that r_1 equals 100,000, I_h equals 30 microamperes, and I equals 0.568 milliamperes, and solving for C_A, the following is obtained.

$$C_A = 2.71 \times 10^{-10} \text{ farads}$$

It will be noted that C_A may also be obtained by subtracting equation (18) from equation (20), this being the ordinary method of measuring capacity as described in Section *B* of the previous paper. Making this subtraction

$$\left(1 + \frac{I_h}{I}\right) r_1 C_A \omega = 0.01038 \qquad (25)$$

From equation (25) we may calculate that $C_A = 2.61 \times 10^{-10}$ farads.

In order to check further their accuracy the authors sent the condenser C_A to an outside electrical laboratory whose measurements of the capacity were 2.53×10^{-10} farads. This check is not perfect, but it is believed to be quite satisfactory, especially in view of the difficulty with which the preliminary balance of the neutralization process with no voltage on the load was made, due to the lack of sensitivity of this instrument.

A NEW TYPE PORCELAIN PROTECTION TUBE

The choice of a proper protection tube for a thermocouple is nearly as important as the selection of the material for the couple. One of the most important properties of such a tube is low porosity to gases, since furnace gases usually attack the couple.[1] There are three general methods of attaining this low porosity: (*a*) By burning a refractory tube to a very high temperature (3000 deg. fahr.); (*b*) by adding a flux (such as feldspar) to a refractory body causing it to vitrify at a considerably lower temperature (2550 deg. to 2700 deg. fahr.); and (*c*) by coating a refractory body, which is not burned at a temperature sufficiently high to vitrify it, with an impervious glaze.

The first method is expensive and not generally practicable, and the second results in tubes which are apt to deform at operating temperatures. The third method produces tubes of satisfactory quality, is comparatively convenient, and has been adapted by this bureau to the production (by the "one-fire" method) of tubes for use in the ceramic laboratory. However, the "freezing" of the glaze to the wall of the furnace, or the ware with which it comes in contact, is a constant source of annoyance and loss of tubes by breakage. This is particularly true of laboratory work, the nature of which does not permit usually of permanent installations of tubes.

The Bureau of Standards has overcome this difficulty by the production of a "double tube" which is highly refractory, satisfactorily rigid at operating temperatures, and which is rendered impervious to gases by a coating of glaze between the double wall of the tube. The tube is formed by casting first a thin tube of the body composition, followed immediately by a cast (or coating) of the glaze, and then a third coating using the body composition to form the inner wall of the tube. When dry, this double-wall tube can be removed from the mold and burned in the usual manner.

THE FLATTEST FLAT

The United States Bureau of Standards has recently completed a flat surface which it claims has a deviation of one-ten-millionth of an inch of being perfectly flat. This is made out of quartz and will be available to American industry generally for test purposes. It is predicted that it will make for more accuracy of the development of intricate mechanical instruments employed in many manufacturing processes especially in the construction of machinery.

This "master quartz flat" will supplant the glass flats previously used by the bureau in testing micrometers and other measuring gauges used by manufacturers. With the glass flats previously used the same degree of accuracy could not be obtained because of its tendency to expand unequally due to heat.

1. Bureau of Standards Tech. Paper No. 170, p. 89

Remote-Controlled Substations

of the New York and Queens Electric Light and Power Company

BY W. C. BLACKWOOD[1]

Member, A. I. E. E.

Synopsis.—This paper describes a unit type of distribution substation which has been designed for a Metropolitan district. Although of much lower capacity than other stations on the same system, its cost per kv-a. is approximately the same as the larger stations. The station is unattended and all operations are controlled from a distant attended station. The cost of operation per unit of capacity is no greater than for a much larger attended station. Remote-control was adopted rather than automatic operation because of the nature of the load and territory served where service with minimum interruption is demanded.

THE New York and Queens Electric Light and Power Company serves four wards in the Borough of Queens, New York City, covering approximately 100 sq. mi. This territory is developing very rapidly both with industrial establishments of all types and sizes and residences varying from small one-family houses to very large apartment buildings.

Energy is purchased from the United Electric Light and Power Company at 13,200 volts and 26,400 volts and is stepped down for 2300/4000 volts., four-wire, distribution in substations located in Long Island City, Flushing, Maspeth and Jamaica, the ultimate capacity of these stations being 75,000 kv-a., 40,000 kv-a., 60,000 kv-a. and 30,000 kv-a. respectively.

In 1925 it was necessary to provide additional substation capacity in the district supplied by the Jamaica Substation, and three means of accomplishing this were considered—first, to increase the size of the present substation at Jamaica; secondly, to build another similar attended station; and thirdly, to build a smaller unattended station for automatic operation or remote control, and to provide for future growth by the erection of other similar unit unattended stations.

A study of these plans indicated that the cost per kv-a. of a large attended station and a small unattended station with automatic features or remote control was approximately the same due to the greater simplicity of the smaller station and the possibility of using switches of lower interrupting capacity than would be required in a large substation where the concentration of power would be greater. It was also found possible to resort to bus regulation in the smaller station, because of the shorter distribution feeders which would be supplied by it, while in the large station it would be necessary to install regulators on the individual feeders with the attendant complication of spare feeder equipment and transfer bus.

If operators were employed the operating cost per kv-a. of the smaller station would, of course, be greater than that of a large station but, if unattended, the operating cost per kv-a., considering periodic inspections which must be made, is estimated to be less than that in the large attended station.

In considering whether an automatic or a remote-controlled substation would be built, the governing factor was the quality of service to be supplied. As demanded in a metropolitan section, it has always been the company's policy to furnish service as nearly free from interruption as possible. Also, the increasing demands upon electric service for such devices as oil-burning equipments, electric clocks, operation of radio and other uses are beginning to make the furnishing of service with 100 per cent continuity imperative. An automatic substation without supervision and control from an attended station would not give the quality of service demanded, and, in order to supply such service, it was decided that all of the operations in the substation should be under the direct and immediate control of an attendant at some point on the system. With such supervision, it was not considered necessary to install automatic features in the station, and the final decision was to build a station with all switches remote-controlled from the nearest attended station and with all operations indicated at that station.

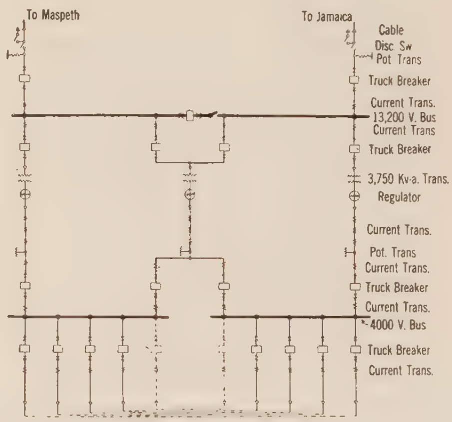


FIG. 1—ONE-LINE WIRING DIAGRAM WOODHAVEN SUBSTATION

The first substation of this type was erected in Woodhaven at a location about 2½ mi. from the Jamaica substation. Three 3750-kv-a., three-phase, oil-insulated, self-cooled transformers were installed and the rated capacity of the station is 7500 kv-a., one transformer being a spare. The station is fed by a 13,200-volt., three-phase 500,000-c.m. underground cable from the Jamaica substation and a similar cable from

1. Of the New York and Queens Electric Lt. & Power Co., Long Island City, New York.

To be presented at the Annual Convention of the A. I. E. E., White Sulphur Springs, W. Va., June 21-25, 1926.

the Maspeth substation approximately 5½ mi. away.

Referring to the wiring diagram, Fig. 1 will show that each incoming cable is connected through oil circuit breakers to a 13,200-volt bus, which is sectionalized at its mid point by an oil circuit breaker. One

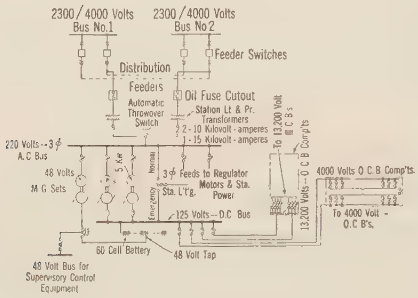


Fig. 2

transformer is connected to each section of this bus through oil circuit breakers, and the third transformer is arranged with double breakers for connection to either section of the bus. The switching connection on the 4000-volt side of the transformers is similar to

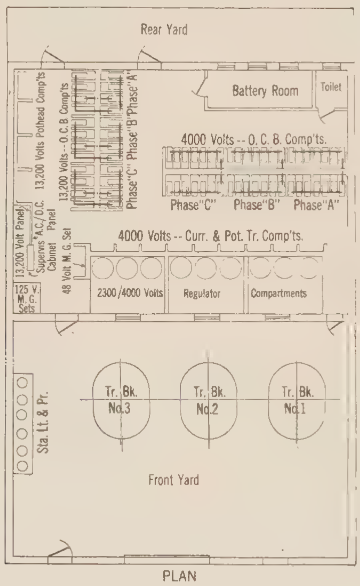


Fig. 3—Plan of Woodhaven Substation

that on the primary side, with the exception that the 4000-volt bus is operated in two sections without a tie breaker. There are four 4000-volt loop distribution feeders, the two ends of each feeder being connected to opposite sections of the 4000-volt bus. Three 135-kv-a., single-phase, automatic induction voltage regulators are connected in the secondary leads of each transformer. The distribution feeders are rated at 400 amperes for a loop feeder, although the switches on each end of the loop have a capacity of 600 amperes.

Each transformer bank is protected by differential relays and the bus sections are similarly protected so that any fault on the bus or its connections will open all breakers connected to the section in trouble. With the loop arrangement of feeders, this will cause no interruption to service.

The bus and switch structures were greatly simplified by the installation of single-phase, truck-type, oil circuit breakers, grouped according to phases both on the 13,200-volt bus and the 4000-volt bus. The transformer switches and 13,200-volt switches are controlled

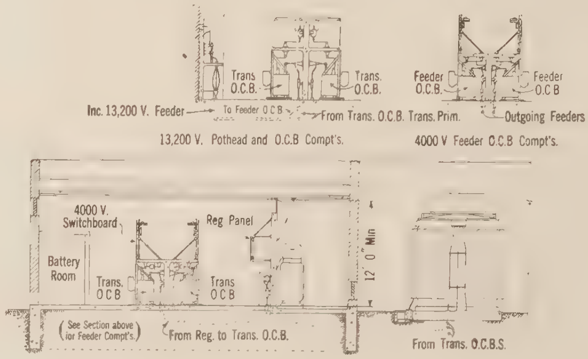


Fig. 4—Sections of Woodhaven Substation

as three-phase units, by electrically connecting the solenoids.

The 4000-volt feeder breakers are operated single-phase. As will be noted from the sectional drawings of the switch compartments, the grouping of all the switches on one phase makes it unnecessary to install three buses and avoids the usual connections from the

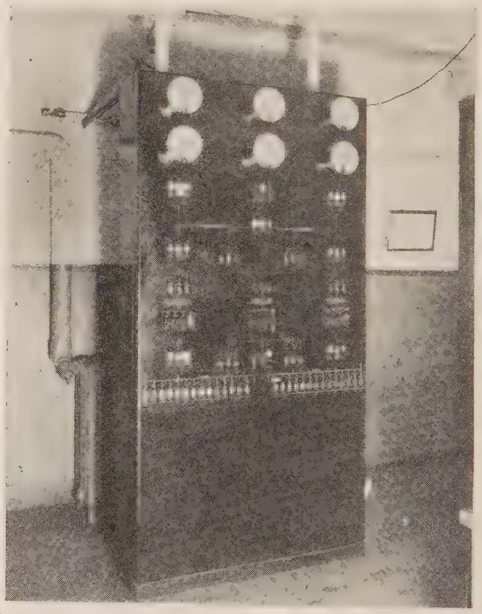


Fig. 5—Panel of Jamaica Substation for Woodhaven Control

bus to the switches which must, in the case of two of the phases, cross other buses if they are arranged in vertical formation.

Fig. 2 is a diagram of the control connections, in the design of which consideration was given to the fact that the station would be unattended and that therefore

continuity of the d-c. supply was essential. Two banks of station light and power transformers are fed from two 4000-volt feeders, tied to opposite bus sections. The secondaries are connected through an automatic throw-over switch to a 220-volt., three-phase bus from which two 5-kw. motor generator sets are fed. Normally,

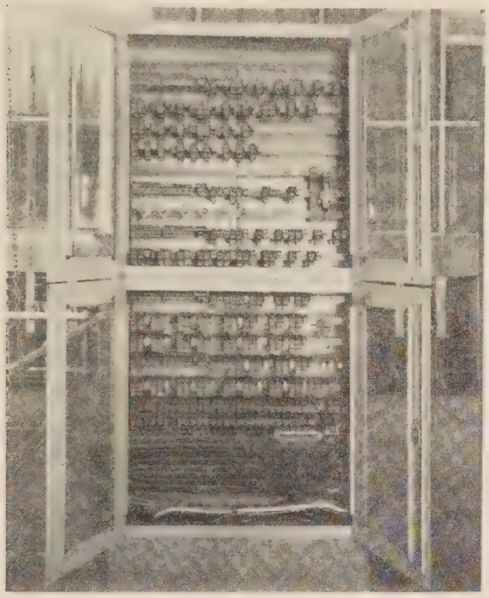


Fig. 6—Supervisory Control Relay Cabinet at Jamaica Substation for Woodhaven Control

one set is in operation, trickle-charging the battery, and relays are provided which, in case of failure of this set, will immediately place the other set in operation.

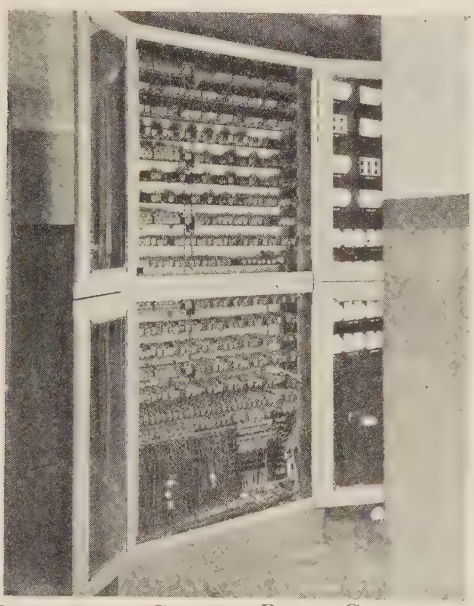


Fig. 7—Supervisory Control Relay Cabinet at Jamaica Substation for Woodhaven Control

A one-kw. motor generator is provided to supply the 48 volts, direct current, required to operate the supervisory control system. In case of failure of this set, connection is automatically made to a 48-volt tap on the station battery. The motor generator set is used for normal operation instead of the battery tap to avoid unequal discharge of the battery.

Sectionalizing switches, but no fuses, are used in the d-c. connections to the oil circuit breaker compartments and all wiring is insulated with 5/32-in. special rubber compound, so installed that grounds or short circuits are practically impossible. This plan was adopted because the blowing of a fuse in an unattended station would probably not be discovered until an attempt was made to operate a breaker and a serious interruption

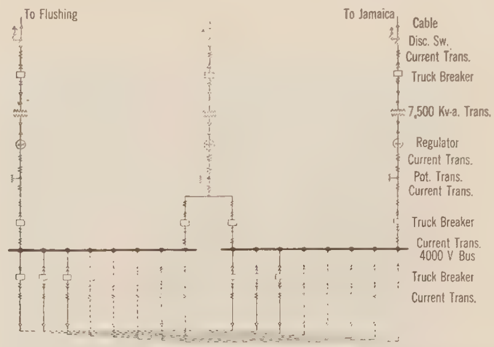


Fig. 8—One-Line Wiring Diagram—Hollis Substation

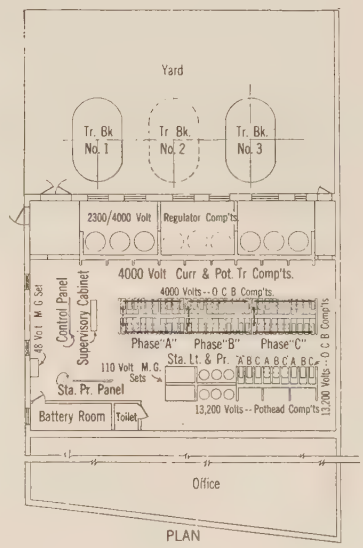


Fig. 9—Plan of Hollis Substation

might result if the d-c. supply to a trip coil was open at the time of a feeder short circuit.

All operations in the station are controlled from a panel in the Jamaica substation shown in Fig. 5. This panel is made of furniture steel and the control keys and indicating lamps are arranged in accordance with the wiring diagram of the Woodhaven station. The control is the Westinghouse Synchronous Relay Visual System, which was described in a paper by Mr. Chester Lichtenberg, presented at the Midwinter Convention in New York, February 8-11, 1926. The relay cabinets at the Jamaica and Woodhaven stations are shown in Figs. 6 and 7. The control cable, which is installed in

under ground ducts throughout, is ten pair No. 19 B&S, paper-insulated and lead-encased.

The supervisory equipment controls 21 single-pole, 13,200-volt breakers and 12 single-pole, 4000-volt breakers, in groups of three, but with single-pole indication at the Jamaica station and 24 single-pole, 4000-volt feeder switches with single-pole indication at the Jamaica station.

It is also possible to read at Jamaica, the current and voltage of each transformer in the Woodhaven station and to operate the regulators from Jamaica to equalize the voltage on the transformers when one is being cut into service.

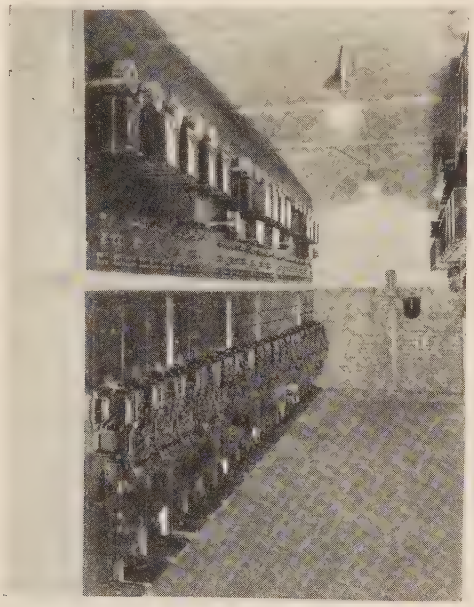


Fig. 10—Woodhaven Substation 4000-Volt Oil Circuit Breakers and Control Panels

Indication is given at Jamaica of high temperature in the transformer windings, ground on the d-c. control system, the operation of the battery charging motor generators and the opening of the station door.

The Woodhaven station has been in operation only a few months and therefore, no definite conclusions can be drawn as to the operation of the supervisory equipment. The installation is probably the most extensive and complicated that has yet been placed in service and there were naturally a number of difficulties encountered in starting it. These were mostly matters of relay adjustment and changes in connections which were found to give back feeds or sneak paths which caused incorrect relay operations. These have been corrected and it is believed that the reliability of operation will be at least equal to that of an attended station.

Construction of a similar station at Hollis approximately eight miles from Jamaica has been started and while the connections and arrangement are substantially the same as at Woodhaven, certain changes have been made which are considered improvements in the design.

The Hollis station will have twice the capacity, or 15,000 kv-a. supplied by two 7500-kv-a. transformers with one 7500-kv-a. spare unit. The diagram of connections is shown in Fig. 8. Each transformer will be supplied by a 13,200-volt incoming feeder with no high-tension bus. With this exception the connections are the same as at Woodhaven. There are of course eight instead of four-loop, 4000-volt feeders.

The arrangement of the bus and switch structures shown in the plan Fig. 9, is slightly different and a control board has been provided at the end of the 4000-volt bus structure on which are located the control switches for the feeder breakers which at Woodhaven are located on the panels directly above the breakers. The relays for each feeder are located on panels above the breakers as at Woodhaven but these panels have been faced in the opposite direction so that access is had from the top of the bus structure instead of from ladders in the switch aisle.

The supervisory control equipment is identical with that used at Woodhaven and the control panel will be placed alongside the Woodhaven panel in the Jamaica substation.

The growth of load in the Borough of Queens is taking place in a number of communities or centers some of which are widely separated and it is probable that the growth will be served by the erection of stations similar to those described above at or near the load centers. Supervisory control equipment, although it has progressed rapidly in the past few years, has been developed principally along the lines of supervision and indication of the operations of automatic stations and has not been depended upon entirely for the complete operation of stations. Much more reliable equipment is needed when the station is not arranged to operate itself automatically in case of failure of the supervisory equipment and while the equipment now available may prove to be satisfactory it will probably be found necessary to change its design in some respects to make it more rugged before the reliability of operation which is demanded in metropolitan districts, is fully realized.

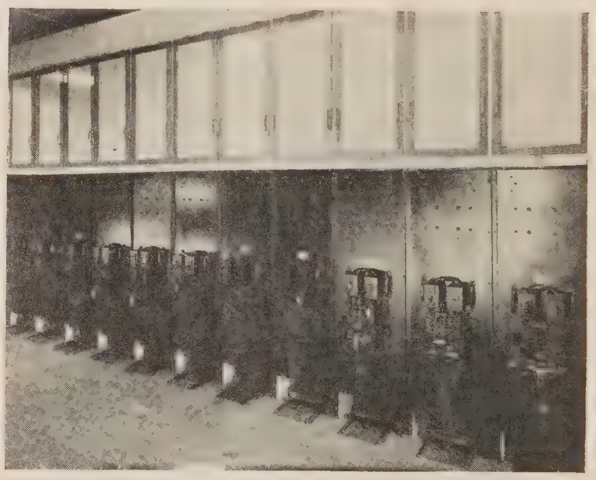


Fig. 11—Woodhaven Substation, 13,200-Volt Oil Circuit Breakers

Abridgment of

Refraction of Short Radio Waves in the Upper Atmosphere

BY WILLIAM G. BAKER[1] and CHESTER W. RICE[2]

Non-member Associate, A. I. E. E.

Synopsis.—*The paper shows that the striking phenomena of short-wave radio transmission (i. e., below 60 meters) can be quantitatively accounted for on a simple electron refraction theory in which the effect of the earth's magnetic field and electron collisions may be neglected as a first approximation. The distribution and number of electrons per unit volume in the upper atmosphere required on this theory to account for the meager experimental data appear to be in general accord with the values required in the explanation of the diurnal variations of the earth's magnetic field, aurorae and long-wave radio transmission.*

The paths taken by the waves from an antenna to distant points on the surface of the earth are calculated. The path calculations give a definite picture of the now familiar skip distance effects. Ideal signal intensity curves (i. e., neglecting absorption and scattering) are given, which show how the energy sent out by a transmitter is distributed over the surface of the earth. A focussing of energy just beyond the skip distance, and again just inside the point where the ray tangent to the ground at the transmitter comes back to earth is clearly shown. The reflection of waves at the surface of the earth is also considered.

The results of these calculations make it possible to estimate the most suitable wave lengths for night and day communication between any two points on the earth's surface. It is also pointed out that there will be a minimum wave length, in the vicinity of 10 meters, below which long distance communication becomes impossible. It is shown that from the point of view of long distance communication low angle radiation is most effective. The ray paths and energy flux density in the wave front of the sky waves are independent of the plane of polarization of the transmitter. The effects of polarization on the reception problem are not discussed.

I. INTRODUCTION

SHORT-wave (*i. e.*, 60 to 15 meters) transmission experiments during the past two years have definitely brought to light many peculiarities which were entirely unexpected as extrapolations from our many years of long-wave experience. Until recently any announcement of long-distance short-wave transmission was put down as an unexplained freak by the average radio man, and dismissed from his mind. As the number of such reports increased, we could no longer be content to dismiss them as freaks and were forced to abandon our preconceived notions as to what normal short-wave transmission should be, and extend our theory in such a way as to give these remarkable results a definite place in the new scheme of things.

In Fig. 1 we have attempted to summarize the available data on short-wave transmission characteristics. Most of the data are from the valuable papers by Taylor[3] and Taylor and Hulburt[4] with a few check points kindly supplied by Young.[5] We have also obtained considerable help, in drawing the smooth curves through the few scattered points, from the valuable work published by many amateurs.[6] The curves assume that 5-kw. are being supplied to an average antenna and that the practical limit of reception is reached at 10 microvolts per meter. The curves further assume full daylight or night conditions at both the transmitter and receiver in order to eliminate sunset and sunrise effects as well as peculiarities which arise when one station is in darkness and the other in daylight. This, of course, limits the diagram to practically north and south transmission; nevertheless, it may be used to estimate the general trend for other conditions.

As a typical example of the peculiarities of short-

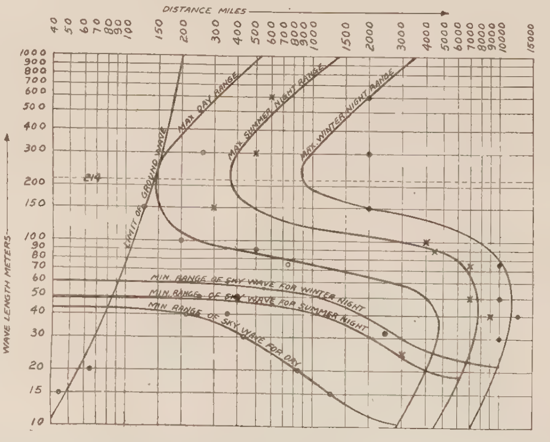


FIG. 1—APPROXIMATE TRANSMISSION CHARACTERISTICS MAINLY FROM DATA BY A. H. TAYLOR FOR 5 KW. IN ANTENNA AND LIMIT OF RECEPTION, 10 MICROVOLTS PER METER. NORTH AND SOUTH TRANSMISSION

wave transmission, let us describe the experience obtained with a 5-kw., 30-meter transmitter. Here the signal rapidly descreases as we leave the transmitter and reaches the lower useful limit of 10 microvolts per meter at about 70 miles. This short range is what might be called the expected value as viewed from our long-wave experience and is represented in Fig. 1 by passing to the right of the line marked *Limit of Ground*

1. W. and E. Hall Fellow of the University of Sydney, New South Wales, Australia. Research Laboratory, General Electric Co., Schenectady, N. Y.
2. Research Laboratory, General Electric Co., Schenectady, N. Y.
3. A. Hoyt Taylor, *Inst. Radio Eng.*, Vol. 13, p. 677, 1925.
4. A. Hoyt Taylor and E. O. Hulburt, *Q. S. T.*, p. 12, Oct. 1925.
5. C. J. Young, Unpublished reports on Short-Wave Transmission Tests by the General Electric Co. at Schenectady, N. Y.
6. See for example *Q. S. T.*, 1924 and 1925.

Presented at the Midwinter Convention of the A. I. E. E., at New York, N. Y., February 8-11, 1926. Copies of complete paper available upon request.

Wave. If we now continue to greater distances the signal remains out until we reach approximately 450 miles where the day signal unexpectedly becomes strong again. This is represented in the figure by crossing to the right of the curve marked *Minimum Range of Day Sky Wave.* Continuing to greater distances we find the signal gradually falling off in intensity, reaching the useful limit of 10 microvolts per meter in the vicinity of 4500 miles by day. This is represented in Fig. 1 by passing to the right of the curve marked *Maximum Day Range.* On a summer night the signal does not reappear after the 70 mile extinction until we are approximately 2000 miles from the transmitter, after which the signal falls off gradually to a very low value at 7500 miles.

The present explanation of the above peculiar phenomena is as follows: Assume, for simplicity, that energy is radiated equally in all directions by the transmitter. As we go away from the source, the signal strength will decrease in the usual manner due to spreading and energy absorption by the ground, with the result that the 30-meter signal practically vanishes in the vicinity of 70 miles. In other words, the ground wave component of the 30-meter signal behaves as we should expect from our long-wave experience, *i. e.*, is rapidly attenuated. The unexpected thing happens when we go out to 450 miles and find that the signal by day has reappeared. This reappearance of signal is accounted for by electronic refraction of a portion of the energy which is radiated towards the sky. A reflection theory of this effect has been proposed by Reinartz.[7] More recently a refraction theory has been developed by Taylor and Hulburt.[4] The calculations in the present paper are based on the electron theory of optical dispersion in metallic media as developed by Lorentz,[8] Drude,[9] etc. We are also greatly indebted to Eccles,[10] Larmor,[11] Appleton[12] and Nichols and Schelleng[13] who have worked out many important conclusions which follow from an application of the optical theory to various phases of the radio transmission problem.

The present calculations show that by making certain reasonable assumptions as to the number and distribution of the free electrons in the upper atmosphere the main characteristics of the relatively meager experimental results can be accounted for.

The calculated paths for rays going out from the transmitter at different angles to the horizontal show the following general characteristics: A ray starting out at a low angle will be only slightly refracted and come to earth again at a great distance from the transmitter. For higher angles the rays will return to earth progressively nearer the transmitter. Finally a critical angle is reached for which the refracted ray comes down at the nearest distance to the transmitter. For higher angles the points of return recede from the transmitter until finally a second critical angle is reached where the ray does not return to earth, but instead goes out into space and is lost.

The distance from the transmitter to the nearest point at which the refracted sky wave returns to earth has been called the "skip distance." For a given wave length the skip distance is a minimum in the middle of the day and a maximum on a winter night, the summer night value being somewhat less than the winter night skip. This variation is theoretically accounted for by a change in the height, thickness and maximum value of the electron density in the upper atmosphere.

The experimental summary given in Fig. 1 shows that the skip distance for a given time of day or night decreases with increasing wave length. This observation is in agreement with the increase in refraction on the longer wave lengths. If we neglect the effect of collisions between the electrons and gas molecules which prevent the refraction index from going to zero, we obtain a sharp upper limit in wave length above which skip distances fall to zero. For the ionization values assumed in the paper, this occurs for a wave length of 60 meters on a winter night as shown in the calculated skip distance curves of Fig. 16.

If the effect of collision frequencies were taken into account, this sharp upper limit would disappear and we would obtain skip distances on wave lengths greater than 60 meters for the assumed winter night ionization values. The effect of the earth's magnetic field will also require consideration in the vicinity of the upper limiting wave length. The experimental determination of skip distances on the longer wave lengths will be difficult owing to the masking effect of a relatively strong ground wave.

On the present theory we may expect severe fading near the transmitter under certain circumstances. For example, consider the case of 60-meter transmission on a winter night. Here a refracted or sky wave will fall inside of the ground wave limit and at a certain distance may be approximately equal in magnitude to the ground wave value. Under these conditions severe interference effects between the two waves will result. If the ground absorption is high this effect may be found quite close to the transmitter. Over salt water the effect should occur at a greater distance.

On shorter waves where the skip distance is well beyond the ground wave limit, severe fading is expected in the region just beyond the skip distance, where the two sky waves of approximately equal intensity overlap.

Appleton[12] and a little later Nichols and Schelleng[13] independently pointed out that the earth's magnetic

7. John L. Reinartz, *Q. S. T.*, p. 9, April 1925.
8. H. A. Lorentz, The Theory of Electrons, Teubner, 1909.
9. Paul Drude, The Theory of Optics (Engl. Trans. by Mann and Millikan) Longmans, 1917.
10. W. H. Eccles, *Proc. Roy. Soc.*, Lond., Vol. 87, p. 79, 1912.
11. Joseph Larmor, *Phil. Mag.*, Vol. 48, p. 1025, 1924.
12. E. V. Appleton, *Proc. Phy. Soc.*, Lond., Vol. 37, Part 2, p. 16D, 1925.
13. W. H. Nichols and J. C. Schelleng, *The Bell System Technical Journal*, Vol. IV, p. 215, 1925.

field should produce some very interesting effects on radio transmission, especially in the vicinity of 214 meters and above. It is interesting to note, in this connection, that Fig. 1 shows a marked absorption in the 214 meter region. A very interesting study of transmission phenomena in the broadcast wave length band, has recently been reported by Bown, Martin and Potter[14]. The present paper is confined to the propagation phenomena on the short-wave side of 214 meters where the effective electron restoring force due to the earth's magnetic field will cease to be important compared with the electron inertia force, and may, therefore, be neglected as a first approximation.

The subject matter contained in the body of the complete paper will be summarized here, by listing the section headings.

II. Refractive Index of a Medium Containing Free Electrons

III. General Equation for the Path of a Ray in a Medium of Varying Refractive Index

IV. Constitution and Distribution of Ionization in the Upper Atmosphere

V. Calculation of the Path of a Ray in a Medium in Which the Electron Density is a Sine Square Function of the Height

VI. Typical Path Calculations

VII. Discussion of Skip Distance Calculations

VIII. Calculation of the Power Received at the Surface of the Earth from a Distant Short Wave Transmitter, Neglecting Energy Absorption

IX. Intensity Calculations

Appendix I

Effect of Electron Collisions with Molecules on the Refractive Index of an Ionized Medium

Appendix II

General Equation for the Path of a Ray in a Medium of Varying Refractive Index in Polar Coordinates

Appendix III

Differentiation of the Range Equation with Respect to θ for the Case of a Curved Earth

Appendix IV

Focusing Effects at the Skip Distance and Inside of the Tangent Ray

X. Summary and Conclusions

We have seen that the striking phenomena of short wave radio transmission *(i. e.,* below 60 meters) can be quantitatively accounted for on a simple electron refraction theory in which the effects of the earth's magnetic field and collisions of electrons with molecules may be neglected as a first approximation. The distribution and number of electrons per unit volume in the upper atmosphere required on this theory to account for the meager experimental data appear to be in general accord with the values required in the explanation of the diurnal variations of the earth's magnetic field, aurorae and long wave radio transmission[28].

Thus the large increase in the skip distance on a given wave length at night compared with that by day is a natural consequence of the greater ionization produced on the sunlit hemisphere by the streamers issuing from the sun. The ideal field intensity calculations given in Fig. 25 show that we may make an ample allowance for scattering and absorption and still account for the strong signals observed at great distances. The high field intensities indicated in the ideal curves of Fig. 25 at the skip distance and where the tangent ray strikes the earth are due to the focussing effect discussed in Appendix IV. The intensities at the two foci will, of course, be limited by the finite size of the source as well as by absorption and scattering.

Let us now discuss the problem of maintaining night and day communication between two points 5000 kilometers apart from the point of view of the present theory. For full winter night conditions *(i. e.,* night at both transmitter and receiver) Fig. 16 indicates that the selection of a 30-meter wave length would put the receiver right at the skip distance. Such a wave length selection would result in the arrival of two intense sky waves and consequently severe fading. Inspection of the field intensity calculations of Fig. 25 show that the field intensity produced by the ray leaving the transmitter at the higher initial angle dies out very rapidly compared with that produced by the ray having the lower initial angle. Therefore, if we pick a somewhat longer wave length than 30 meters we will receive a reasonably strong signal from one ray only and consequ ntly be less likely to find severe and rapid fading effects. We would, therefore, probably choose a wave length in the vicinity of 32 meters for winter night operation.

An alternative would be to select a wave length in the vicinity of 55 meters, with the idea of taking advantage of the focussing which occurs just inside of the distance at which the ray leaving the transmitter tangent to the ground comes back to earth. For full day conditions this wave length would be weak since 5000 kilometers is too far from the day skip distance. If we applied the above reasoning in selecting the best value for full day operation from Fig. 16 we would probably be led to select a wave length in the vicinity of 11 meters. This, however, would bring us down very close to the lower wave length limit which would mean a very weak signal. The reason for the weak signal near the low wave length limit will be readily appreciated when we remember that under these conditions we are working close to the value at which

14. Ralph Bown, De Loss K. Martin and Ralph K. Potter. *The Bell Syst. Tech. Jour.*, Vol. V, No. 1, p. 143, 1926.

28. H. J. Round, T. L. Eckersley, K. Tremellen and F. C. Lunnon. *Journ. Inst. Elec. Engg.*, Vol. 63, No. 346, p. 933, Oct. 1925.

a ray leaving the transmitter tangent to the earth's surface strikes the lower boundary of the ionized medium at the second critical angle. Under these conditions there is only a small fraction of the emitted radiation which returns to earth.

It would, therefore, be better to select a wave length in the vicinity of 15 meters and operate on the ray which is reflected from 2500 kilometers to 5000 kilometers. Under these conditions we would, of course, face the possibility of considerable fading due to interference between the weak direct ray and the reflected ray. Another method would be to use a still longer wave length, for example around 25 meters, and depend upon the reflection of the energy falling at 2500 km. which is already beginning to pile up towards the focus at 3500 km.

In this connection it is interesting to note that the reflected 25 meter signal should be much stronger at 6400 km. than at 5000 km. since the focus is in the vicinity of 3200 km. In other words, it is apparently easier to get a good day signal at 6400 km. than at 5000 km. This point of view indicates that in short wave transmission problems, there will be certain favored distances. Another point of interest is that a 28 meter wave length should give good day and night communication between two points about 6400 km. apart due to the direct ray by night and the reflection from the tangent ray focus by day.

The numerical values deduced for this example are, of course, very uncertain since the ionization constants for the upper atmosphere which are required before a set of radio transmission characteristics like Fig. 16 can be calculated were figured backward from the very meager radio data. In other words it is probably fair to say at the present time that short wave radio transmission experiments are the most direct method we have of estimating the ionization conditions in the upper atmosphere. We should not lose sight of the fact that the skip distances, etc., which depend upon the ionization conditions in the upper atmosphere are probably not constant but will vary from year to year following the 11 year sun spot period, the last minimum of which occured in 1922.

When both the transmitter and receiver are not in the sunlit or darkened hemisphere the ray paths will no longer be symmetrical about the middle point, and due allowance will have to be made for the variation of ionization conditions between the two stations. Sunset and sunrise effects will also require special treatment. It is also probable that transmission to or from the polar regions will require special study of this kind, due to the high concentration of ionization over the polar regions as compared with that over the middle belt of the earth. We can conclude in a general way that transmission from the sunlit into the darkened hemisphere will result in longer skip distances than would result if daylight extended over the whole path. For example, a ray entering the ionized medium from the sunlit side will at first meet the normal day refraction, which starts bending the ray back towards the earth and, as it moves into the darkened hemisphere, the bending by refraction will become less and less until normal night conditions exist. Thus the ray will strike the ground at a greater distance from the transmitter than it would have, if full day conditions extended over the entire path. Here the general conditions for reciprocity[29] are satisfied, so that if a ray were started back along the same path it would retrace the entire path back to the starting point.

Inspection of the day curve of Fig. 16 shows that it will be impossible to maintain communication between two distant stations on less than a 10-meter wave length. This limitation is due to the fact that the tangent ray will strike the lower boundary of the ionized medium at an angle greater than the second critical angle and will therefore not return to the earth, but be refracted out into empty space.

The precise value of this minimum wave length is, of course, not 10.6 meters, as indicated in Fig. 16, because of the meager data upon which the figure is based. There is a similar limit for full winter night conditions given as 22.5 meters in Fig. 16. Near sunset or sunrise we can, however, use a wave length less than the above full winter night limiting value, when transmitting from the dark into the light hemisphere, since the refraction is increasing in the direction of travel of the ray and may be sufficient to bend the ray back to earth.

It is now interesting to see what type of antenna directive curve will be most effective for long distance communication from the point of view of the present theory. We have seen that all of the energy which strikes the lower boundary of the ionized medium above the second critical angle is refracted out into space and is lost. The initial angle at the transmitter which corresponds to this condition is obtained from equations (80) and (97) as

$$\theta = \cos^{-1} \{ (1 + b/r_0) \sqrt{1 - \sigma N_0/\omega^2} \}$$

which may be written for convenience as

$$\theta = \cos^{-1} \{ (1 + b/6300) \sqrt{1 - 9 \times 10^{-9} N_0 \lambda^2} \}$$

The summer day and winter night conditions on long wave lengths yield the largest useful values of the initial angle. For our assumed ionization condition we obtain $\theta = 67.8$ deg. for 40 meters on a summer day and $\theta = 64.5$ deg. for 55 meters on a winter night. For shorter wave lengths the critical values for the initial angles will be much less, as will be seen from Figs. 23 and 26. Here $\theta = 25.9$ deg. for 21 meters on a summer day and $\theta = 11.2$ deg. for 25 meters on a winter night. Thus we may conclude that on these

29. Cases where two way communication on the same wave length will not hold, due to the effect of the earth's magnetic field, or because of an electron drift velocity, have been discussed respectively by E. V. Appleton, *Nature*, p. 382, March 7, 1925, T. L. Eckersley, *Nature*, p. 466, Sept. 26, 1925.

short wave lengths all of the useful radiation is emitted between the horizontal and approximately 70 deg., and the greatest distances are reached by the low-angle radiation. We therefore conclude that for long-distance work, on short waves, maximum efficiency is obtained by low-angle radiation. This also means that nearby obstructions which cut off the low angle radiation will be detrimental to long distance working. It is therefore desirable to place the transmitter on a hill or mountain, so as to obtain an unobstructed path to the horizon in the desired direction. Raising the antenna system well above the ground will also assist by reducing ground losses and lowering the horizon.

For long distance work the plane containing the electric vector at the transmitter may make any angle whatever with respect to the ground without appreciably affecting the ray paths or energy flux density in the wave front.

In any case the earth's magnetic field will produce enough rotation of the plane of polarization to make the angle of polarization of the received ray at the surface of the ground purely a question of chance. The best type and orientation of receiving system (loop or antenna) will depend upon the direction and polarization of the arriving wave as well as upon the conductivity of the ground and height of the receiving system above the earth. Some interesting work on determining the direction of arrival of signal waves has recently been done by Appleton and Barnett[30].

The best polarization of the transmitter can therefore be considered from the point of view of ground losses, mechanical construction and such questions as nearby interference, due to the ground wave, etc.

It should be pointed out in closing that electron collisions and the effect of the earth's magnetic field will modify the shape of the skip distance curves in the vicinity of the upper asmptotic wave length. Here absorption and double refraction (*i. e.*, splitting of a ray into two components having different velocities of propagation) will require consideration in a complete theory of short wave transmission.

The above theory is based on continuous wave theory and will not apply directly to very highly damped waves. In highly damped spark transmission we are dealing with a wide band of frequencies and therefore skip distance effects, etc., will be considerably blurred. Here methods similar to those used by Eckersley[31] in his very interesting explanation of the familiar "trolley car noise" often heard by radio men, would have to be applied.

The relatively small effect of molecular refraction, due to density and temperature gradients in the lower atmosphere, discussed by Fleming[32] and Larmor[11] has been neglected.

It should also be kept in mind that only an approximate allowance has been made for the curvature of the ionized medium on the ray effect of the paths.

ACKNOWLEDGMENT

The writers owe a great deal to Mr. E. W. Kellogg for the many illuminating suggestions which he contributed during the preparation of the paper.

30. E. V. Appleton and M. A. F. Barnett, *Proc. Roy. Soc. A*, Vol. 109, p. 621, Dec. 1925.

31. T. L. Eckersley, A Note on Musical Atmospheric Disturbance, *Phil. Mag.*, Vol. 49, p. 1250, June, 1925.

32. J. A. Fleming, *Proc.* Phy. Soc. Lond., Vol. 26, p. 318, 1913-1914.

GERMAN-LUXEMBURG POWER SCHEME

The sites for two plants of the Ours River hydroelectric scheme, are to be such that one plant will be in Germany and the other just across the border in Luxemburg. At the point where the dam is to be built, the valley is narrow and the conditions favorable. The dam will be 106 meters high, and the average flow is 30 cubic meters per second. The impounded water will back up a distance of 28 kilometers, and flood 20 square kilometers, as well as six towns. In order to obtain more water than the Ours River itself supplies, water will be carried by pipe line from the Kyll River at Birresborn (elevation 335) to the Prum River (elevation 325) at Waxweiler, thence to the Irsen River (elevation 318) and finally to the Ours River. Water will also be drawn from the Sauer River.

Plans for Supplying Power

The new company intends to supply power only during the day and to store the water at night. During the night they may purchase cheap power and pump water back into the lake, as the day power rate is about 4½ times the night rate. A reserve supply of 200,000,000 cubic meters of water can be stored in the reservoir.

The power will be used in Luxemburg and the Rhine Provinces. Transmission lines will be built to Cologne (107 kilometers, 200,000 volts), connecting with the Goldenburg company at Duren, Trier (45 kilometers, 100,000 volts), Eteburck (50 kilometers), and Luxemburg City. When the work is completed, the company will be able to generate 400,000 kilowatt hours per day, which may be increased to 600,000. Should the demand for power increase, another plant can be erected below the present dam, giving a further capacity of 60,000 kilowatts. There are a few small power plants in the neighborhood which now produce together about one-fortieth of what the new company will be able to generate.

Current Transformers with Nickel-Iron Cores

BY THOMAS SPOONER[1]

Member, A. I. E. E.

Synopsis.—There has been developed recently a nickel-iron alloy called hypernik which has especially low hysteresis loss and high permeability at low inductions. Due to these properties the material is particularly suitable for the cores of current transformers. A ring-type series transformer with a core of hypernik has approximately one-third of the ratio and phase-angle errors exhibited by a similar transformer having a core of ordinary silicon steel.

The relative performance of transformers with cores of the two kinds of material are shown by test and by calculation for various burdens and ratios. The minimum ratio for which satisfactory performance can be obtained with a through-type transformer having a hypernik core is about 200 to 5.

This new material is relatively expensive but its use will undoubtedly be warranted for certain applications.

THE accurate metering of power supplied at high voltages is difficult due to limitations in the performance of through-type current transformers. With a single turn for the primary the available m. m f. for low currents is very small. For a standard five-ampere secondary winding the number of secondary turns is fixed by the ratio, therefore, for a given burden inductions in the cores are high which means relatively large core losses and magnetizing currents. As the transformer ratio decreases the phase-angle errors rise very rapidly due to losses and the low permeability at low inductions for the ordinary silicon-steel core materials.

Some years ago L. W. Chubb recognized the possibility of improving the performance of current transformers by the use of certain nickel-iron alloys which have especially high permeability at low inductions.[2] Such a material has now become commercially available through the efforts of T. D. Yensen and P. H. Brace.

The purpose of this paper is to show some of the advantages which may be gained by the use of a particular nickel-iron alloy called hypernik for the cores of through-type transformers.

Current Transformer Characteristics

If the magnetic properties of the core of a current transformer and the leakage reactances of the windings are known, the ratio and the phase-angle errors for any secondary current or burden on the transformer; may be calculated quite accurately. Since this particular discussion is limited to through-type transformers, the effect of leakage reactance will be neglected since this is practically negligible for this type of transformer.[3]

In order to calculate the performance of ring-type transformers, it is necessary then to know only the watt and wattless components of magnetizing current for the particular core at the desired frequency and induction as determined by the secondary current and burden. A method of measuring the core characteristics will be discussed later.

The relation between the magnetic properties of the core and transformer performance has been shown very clearly by Agnew.[4] Fig. 1 shows the vector diagram of a current transformer supplying an inductive load.

E_2 is the secondary voltage.

I_1 and I_2 are the primary and secondary currents, respectively.

n is the ratio of the number of secondary to primary turns.

φ is the phase angle of the secondary current.

M is the magnetizing component of the core exciting current necessary to produce the flux Φ.

F is the corresponding loss component of exciting current (due to hysteresis and eddy losses in the core).

Because of the magnetizing and loss components of the exciting current there will result (unless the exciting current is in phase opposition with the secondary current) a phase angle between the primary and secondary currents which will differ from 180 deg. by the angle θ. This is the phase-angle error of the transformer. The ratio error is proportional to the difference between I_1 and $n\,I_2$.

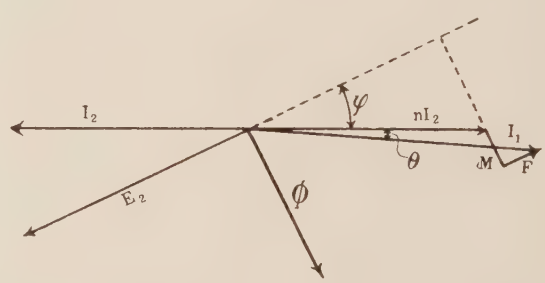


Fig. 1—Vector Diagram of Current Transformer

Agnew gives the following simplified formulas for calculating the errors in current transformers.

$$\text{Ratio } (R) = n + \frac{M \sin \varphi + F \cos \varphi}{I_2} \tag{1}$$

1. Research Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

2. U. S. Patent Number 1,277,384.

3. Effect of Magnetic Leakage in Current Transformers. H. W. Price, C. K. Duff.

Papers on Current Transformers. *Bull.* No. 2, Section No. 4, University of Toronto, 1921, p. 169-171.

4. A Study of the Current Transformer with Particular Reference to Core Losses. P. G. Agnew, *Bull.* Bureau of Standards, Vol. 7, 1911, pp. 423-474.

Presented at the Regional Meeting of District No. 1 of the A. I. E. E., Niagara Falls, N. Y., May 26-28, 1926.

$$\text{Tan } \theta = \frac{M \cos \varphi - F \sin \varphi}{n I_2} \tag{2}$$

Obviously if φ is 0, namely, if the burden on the secondary of the transformer is non-inductive,

$$R = n + \frac{F}{I_2} \tag{3}$$

$$\text{Tan } \theta = \frac{M}{n I_2} \tag{4}$$

In other words, for this case and a given secondary current the ratio depends only on the ratio of the secondary to primary turns and the loss in the core. The phase angle depends only on the same turn ratio and the magnetizing current or permeability of the core material.

A material is desired, therefore, which has low losses

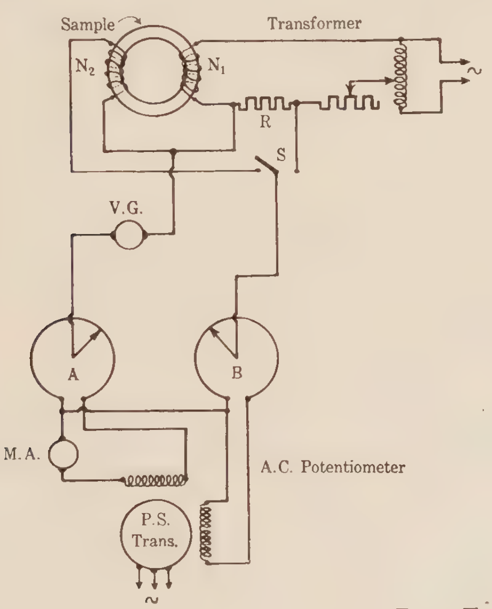


Fig. 2—Diagram of Connections for Ring Testing

and high permeability at low inductions. It is such a material which has now become available.

Determination of Magnetic Properties of Core Materials

In order to predetermine the performance of a given design of a current transformer under definite conditions of load, it is desirable to have curves for the specific kind of core material which is to be used, giving the watt and wattless components of the exciting current plotted against induction. Such data can be obtained by supplying a sample of core material with a winding or windings, applying different voltages of the desired frequency and measuring the current and watts by means of sensitive indicating instruments. For very low inductions this is rather a difficult and tedious process since the wattmeter must be very sensitive and corrections must be made for the instrument losses.

A much quicker and simpler method is to use a Tinsley-Gall, a-c. coordinate potentiometer.[5] The use of this instrument for such a purpose has been described recently.[6] The method of test is shown in Fig. 2.

The a-c. potentiometer, itself, is shown schematically. It consists of two distinct potentiometers supplied with currents which are equal in magnitude but differ 90 deg. in phase. These currents are obtained from a phase-shifting transformer having a two-phase secondary winding. Voltage balance is indicated by means of a vibration galvanometer. The sample, which is shown in ring form, is provided with primary and secondary windings N_1 and N_2. A-c. current of the desired frequency is supplied from a convenient source through a regulating transformer and a series resistance. This source is the same as that which supplies the primary of the phase-shifting transformer. The primary current I_1 is first adjusted to some convenient value and switch S is thrown to the left, thus connecting the potentiometer to the secondary winding N_2. Potentiometer B is set to O and the phase-shifting transformer and potentiometer A are then adjusted for O reading of the vibration galvanometer $V\,G$. When this adjustment is completed, A gives the magnitude of the secondary voltage and from it the induction in the sample can be calculated as follows, assuming a sine wave of voltage, which is nearly true for low and moderate inductions assuming approximately a sine-wave supply of current. This assumption is far from true, however, for high inductions.

$$B = \frac{E_2 \times 10^8}{A \times N_2 \times f \times 4.44} \tag{5}$$

where,

B is the induction in gausses
E_2 is the voltage induced in the secondary
A is the cross section of the specimen in sq. cm.
N_2 is the number of secondary turns
f is the frequency.

Next, S is thrown to the right connecting the potentiometer across the terminals of the shunt R. Then potentiometers A and B are adjusted for a vibration-galvanometer balance. The reading of A is now proportional to the loss component of the current in the primary and the reading of B is proportional to the wattless or magnetizing component of the current. If R equals 1 ohm, the readings of A and B are directly in amperes. This operation may be repeated for as many inductions as is desired. If more convenient a single winding only may be used on the sample, provided it has a negligible resistance.

If now the magnetizing current is multiplied by the

5. A New A-c. Potentiometer, by D. C. Gall, *Electrician*, Vol. 90, April 6, 1923, p. 360.

6. Some Applications of the A-C. Potentiometer, T. Spooner, *Journ.* Optical Society of America and Review of Scientific Instruments, March 1926, p. 217.

voltage and divided by the weight of the sample in pounds, there will result the wattless volt-amperes per pound for the material. Similarly the watt component of current gives the watts per pound. This is on the assumption that N_1 and N_2 are equal. By using a sufficiently large sample, data have been obtained by this method for a range of inductions from a few gausses to several thousand gausses, both at 25 and 60 cycles.

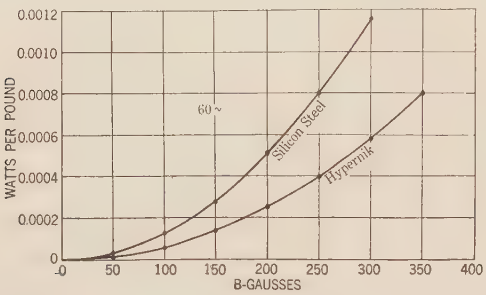


Fig. 3—Core Loss of Ring Punchings

Ring Dimensions = 5-7/8 in. by 3-5/8 in.

Figs. 3 to 6 show the watt and wattless volt-ampere for 60 and 25 cycles for a good grade of four per cent silicon steel as compared with a rather poor specimen of hypernik. The thickness of laminations was 0.014 in. (0.0356 cm.). These particular curves cover a rather limited range of inductions but indicate clearly the difference in the properties of the two kinds of material. The marked superiority of the hypernik is obvious. For actual design purposes it is more convenient to

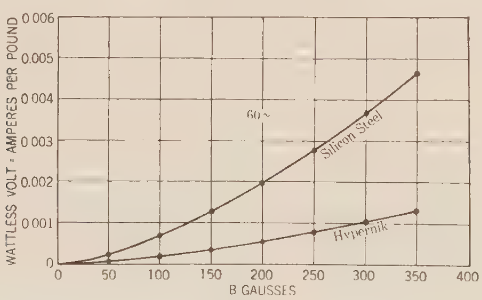


Fig. 4—Magnetizing Current of Ring Punchings

Ring Dimensions = 5-7/8 in. by 3-5/8 in.

plot the results on double-log paper since a much larger range of inductions can be covered with less confusion of scales.

The Calculation of Performance. Using the magnetic characteristics of the material as given by such curves as shown in Figs. 3 to 6, and by using formulas (1) and (2), it is a very simple matter to predetermine the characteristics of a through-type transformer. The method will be illustrated by an example and the results compared with actual test values. The following constants apply to a transformer actually built and tested at 60 cycles.

Core Material.

Hypernik

Rings: 5⅞ in. (14.9 cm.) outside diameter; 3⅝ in. (9.2 cm.) inside diameter

Weight: 10 lb. (4.54 kilograms)

Cross section of core (density 8.3) = 14.22 sq. cm.

Secondary Windings.

Turns: $(N_2) = 100$

Resistance = 0.109 ohms

Burden

15 volt-amperes at 80 per cent power factor (resistance 0.480 ohms)

Inductance = 956 microhenries.

The total resistance to be considered in calculating the

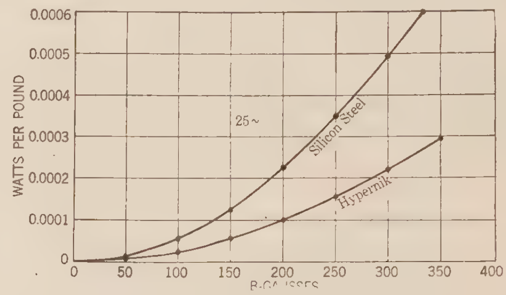


Fig. 5—Core Loss of Ring Punchings

Ring Dimensions = 5-7/8 in. by 3-5/8 in.

performance must include the secondary resistance of the transformer winding, therefore,

$R = 0.109 + 0.480 = 0.589$ ohm.

$X = 2\pi f \, 956 \times 10^{-6} = 0.360$ ohm.

$\sqrt{R^2 + X^2} = 0.690$ ohm

$\tan \varphi = 0.611$

$\sin \varphi = 0.521$

$\cos \varphi = 0.853$

One ampere in the secondary, therefore, corresponds

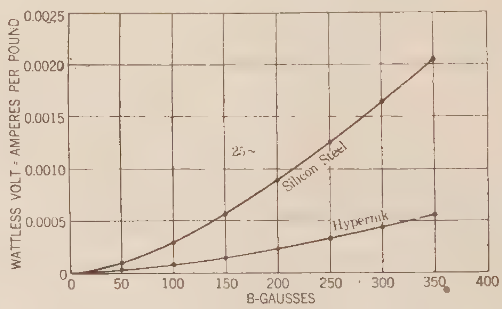


Fig. 6—Magnetizing Current of Ring Punchings

Ring Dimensions = 5-7/8 in. by 3-5/8 in.

to 0.690 volts and from this the inductions can be calculated by the ordinary transformer formula (5).

TABLE I

CALCULATION OF TRANSFORMER PERFORMANCE

			per lb.						
I_2	E_2	B	VA	W	M	F	R	$\tan \theta$	θ
0.5	0.345	91	0.00015	0.000049	0.435	0.142	1.0069	0.00590	20′
1	0.690	182	0.00047	0.00021	0.681	0.304	1.0060	0.00422	14′
2	1.380	364	0.00140	0.00086	1.014	0.624	1.0053	0.00270	9′
3	2.070	546	0.00259	0.00200	1.250	0.966	1.0049	0.00188	7′
4	2.760	728	0.00393	0.00348	1.424	1.261	1.0045	0.00141	5′
5	3.450	910	0.00540	0.00530	1.566	1.537	1.0042	0.00107	4′

The wattless volt-amperes per pound, VA, and the watts per pound, W, were obtained from curves similar to those given by Figs. 3 and 4, but covering a greater range of inductions. In order to obtain M and F, it is simply necessary to multiply VA and W, respectively, by $\frac{N_2 W_t}{E_2}$ where W_t is the weight of the core material in pounds. R and $\tan\theta$ are then obtained directly from formulas (**1**) and (**2**).

This detailed analysis has been followed through

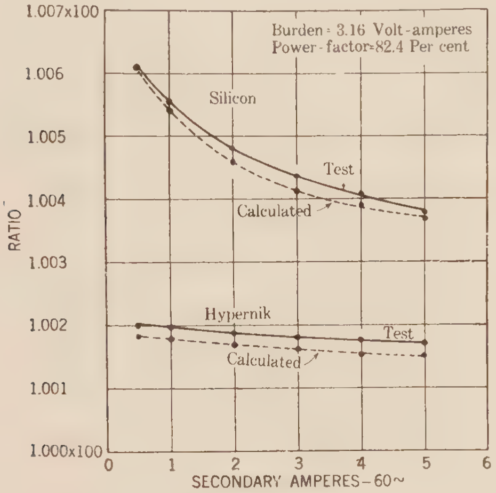


Fig. 7—500-5 Ring-Type Current Transformers
Burden = 3.16 volt-amperes
Power factor = 82.4 per cent

since it has been observed that a person not familiar with this type of calculation is very likely to make a mistake in applying the various formulas.

Check Values

Two transformers exactly alike, except that one had a silicon-steel core and the other a core of hypernik,

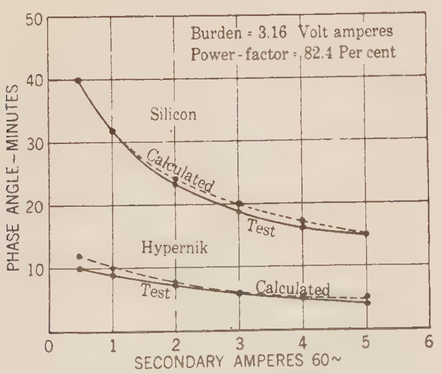


Fig. 8—500-5 Ring-Type Current Transformers
Burden = 3.16 volt-amperes
Power factor = 82.4 per cent

were constructed according to the above specifications, each core weighing 10 lb. They were sent to the Bureau of Standards for check at 60 cycles and two burdens, namely 3.16 volt-amperes and 15 volt-amperes. It may be noted that the net inductions in the two cores were slightly different although the fluxes were identical since silicon steel has a density of about 7.5 and hypernik of about 8.3.

The test and calculated results are given by Figs. 7 to 10. The checks are probably about as close as could

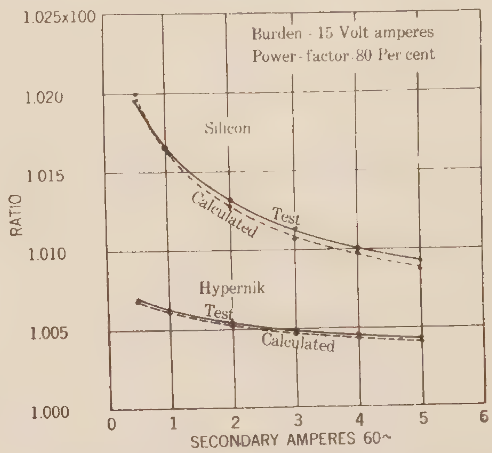


Fig. 9—500-5 Ring-Type Current Transformers
Burden = 15 volt-amperes
Power factor = 80 per cent

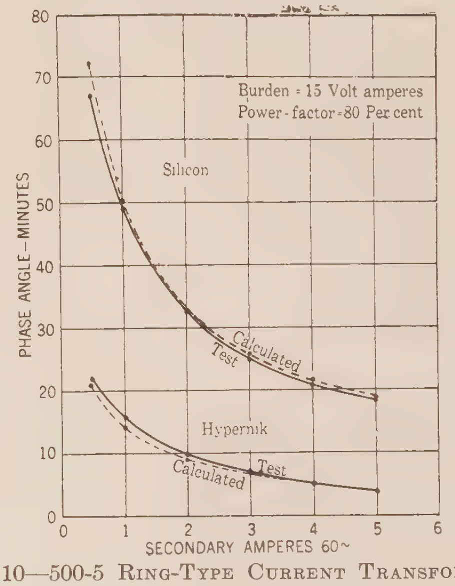


Fig. 10—500-5 Ring-Type Current Transformers
Burden = 15 volt-amperes
Power factor = 80 per cent

be expected and are in general very good. Before calculating the performance, the magnetic quality of the core material was checked on a completed transformer at two or three inductions by means of the a-c. potentiometer and where the results departed appreciably from the curves of Figs. 3 and 4, parallel curves were drawn from which the magnetic data were obtained.

Relative Performance of Transformers for Various Ranges

Having shown that it is possible to calculate the performance of this type of transformer with approximately the same accuracy as it can be tested, we are now in a position to show by calculation what can be expected

for various ranges. Figs. 11 to 15 give the comparative ratio and phase-angle curves for silicon and hypernik transformers for various ranges of secondary current from 200 to 1500 amperes, using various burdens and weights of core material. The very considerable superiority of hypernik over the silicon steel is seen for these conditions. In comparing the ratio curves it should be remembered that by means of turn compensation the actual ratio curves may be reduced much closer to unity by this means. It will be noted, however, that this compensation will not be nearly as effective for the silicon-steel transformers since the ratio curves are not nearly as flat as for the hypernik. The phase-angle

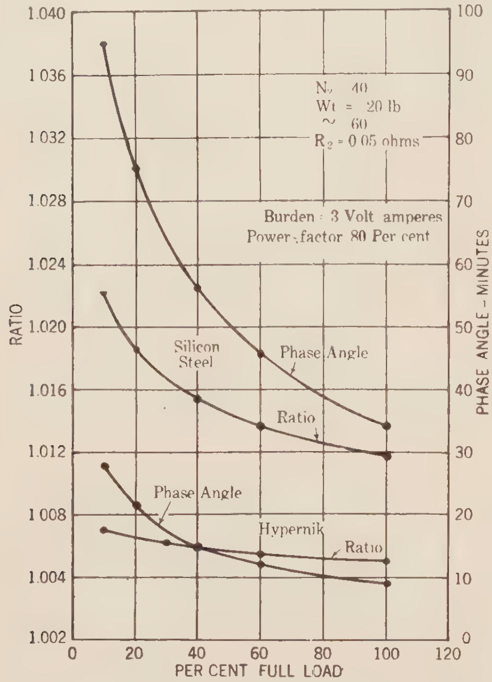


Fig. 11—200-5-Current Transformers

Burden = 3 volt-amperes
Power factor = 80 per cent
N_2 = 40
Wt. = 20 lb.
~ = 60
R_2 = 0.05 ohms

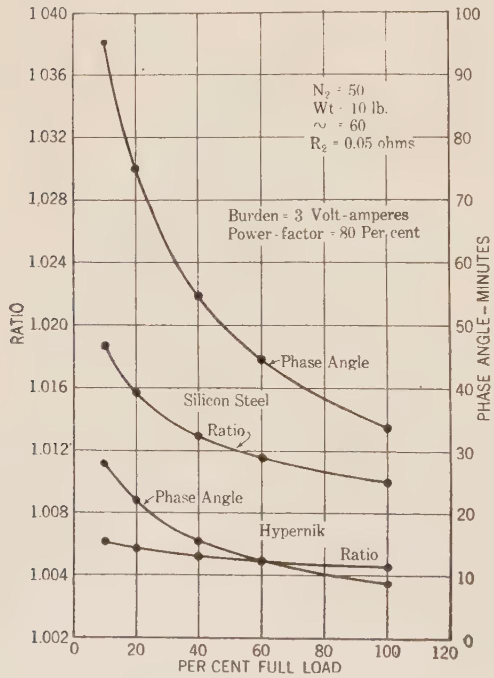


Fig. 12—250-5 Current Transformers

Burden = 3 volt-amperes
Power factor = 80 per cent
N_2 = 50
Wt. = 10 lb.
~ = 60
R_2 = 0.05 ohms

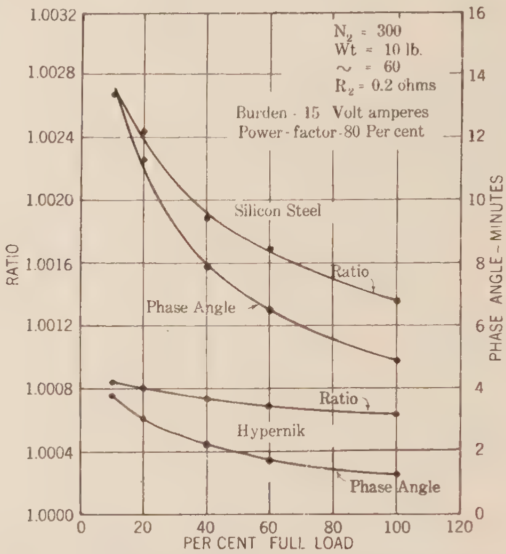


Fig. 13—1500-5 Current Transformers

Burden = 15 volt-amperes
Power factor = 80 per cent
N_2 = 300
Wt. = 10 lb.
~ = 60
R_2 = 0.2 ohms

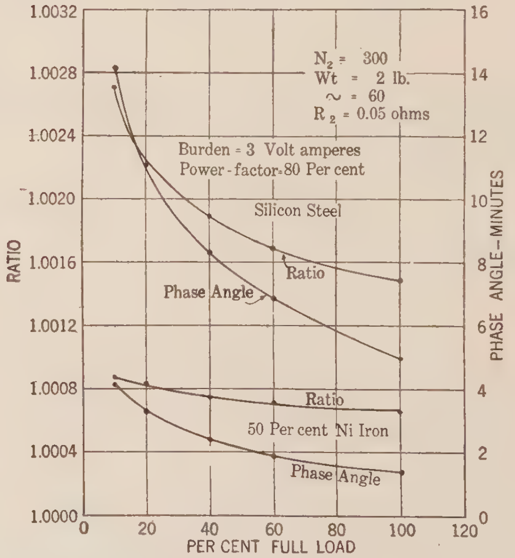


Fig. 14—1500-5 Current Transformers

Burden = 3 volt-amperes
Power factor = 80 per cent
N_2 = 300
Wt. = 2 lb.
~ = 60
R_2 = 0.05 ohms

errors will not be affected much by turn compensation. Of course, compensation for phase-angle and ratio errors can also be effected by means of parallel non-inductive or capacity shunts, but this is rather unsatisfactory since an adjustment has to be made for each burden.[2]

As an indication of the burdens which may be im-

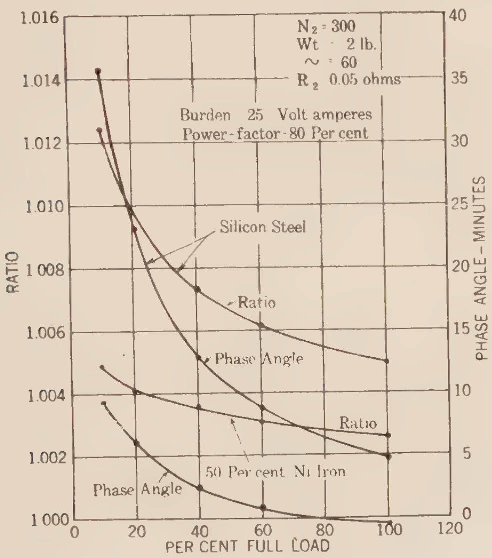


FIG. 15—1500-5 CURRENT TRANSFORMERS

Burden = 25 volt-amperes
Power factor = 80 per cent
N_2 = 300
$Wt.$ = 2 lb.
~ = 60
R_2 = 0.05 ohms

posed on a current transformer it may be mentioned that a watthour meter requires from one to two volt-amperes at full load and a switchboard ammeter about three volt-amperes. Relays and recording instruments may take 15 volt-amperes or more.

CONCLUSIONS

A new core material for current transformers has been made available which for the same weight of core reduces the ratio (assuming no compensation) and phase-angle errors to approximately one-third of those resulting from the use of ordinary silicon steel. This material is much more expensive than silicon steel but for large installations, where considerable blocks of power need to be measured accurately, the extra cost would be insignificant as compared with the value of the improved accuracy of measurement. Where there are space limitations, if desired, a smaller amount of core material could be used giving the same performance as for the silicon steel and at approximately the same cost, but resulting in a smaller transformer.

The gain to be expected by the use of hypernik for the cores of transformers, using L-shaped punchings, would not be as great as for ring-type punchings, due to the decreased permeability resulting from the gaps. Even here, however, for the same size of transform are considerable improvement by the use of the new iron would result. The use of hypernik in through-type transformers will perhaps be the most important application since it is in this case that the transformer designer finds his chief difficulty in obtaining good performance. In this connection, however, it may be mentioned that hypernik is of no value for the cores of through-type transformers operating very heavy-burden relays since it saturates at a considerably lower induction than silicon steel. It is only at the lower inductions, namely, for meter loads, that its superiority manifests itself.

The application of this material for improving current-transformer performance is extremely simple since it involves no changes in the general transformer design and no changes in the existing meters.

MUSCLE SHOALS

The Joint Congressional Committee on Muscle Shoals has decided to recommend acceptance of the bid of the Muscle Shoals Fertilizer Company and the Muscle Shoals Power Distributing Company. The terms of the proposal submitted by the above bidders have been written into House Bill 11602 which is awaiting action in the House of Representatives. It is also understood that the acceptance of this proposal has the approval of the President and the Secretary of War.

It will be recalled that the Muscle Shoals Fertilizer Company and the Muscle Shoals Power Distributing Company represent a combination of fourteen public utility companies which have previously been interested in the use of the Muscle Shoals power.

No estimate is possible at this time as to how soon this proposed legislation will be acted upon although it is now felt no action will be taken during this session of the 69th Congress.

FEDERAL POWER COMMISSION WILL NOT INTERFERE WITH STATES RIGHTS

The case of the New York State in its control of the waters of the Niagara River, being handled before the Federal Power Commission by former Secretary of State, Charles Evans Hughes, has brought a pointed statement from the Federal Power Commission in which the members reiterated their desire not to interfere with the rights of states in the regulation or development of navigable waters in their boundaries. The project calls for the development of hydroelectric power in the Gorge below the Falls of Niagara and below the "Maid of the Mist" pool, in Niagara County, where the above named company plans to erect its power house and dam.

Mr. Hughes, in his letter, discusses at length the commission's proposed license and states that the Attorney-General of New York holds that its provisions "would constitute an invasion of authority of the State."

The Retardation Method of Loss Determination
as Applied to the Large Niagara Falls Generators

BY J. ALLEN JOHNSON[1]

Associate, A. I. E. E.

Synopsis.—*Institute literature is apparently lacking in information regarding retardation tests. The purpose of this paper is to point out certain advantages of the method and to describe the procedure followed in testing the Niagara generators.*

The basis of the method is first given with the fundamental formula upon which it depends. Since it requires the use of the moment of inertia, or "fly-wheel effect," $W R^2$, methods of determining this value are given, and it is pointed out that it can be determined by test.

The methods of determining the speed of rotation and its rate of change are given, with a description of the devices used for automatically recording the necessary data and the method of interpreting such data. It is shown how the determination of losses over a range of speeds increases the accuracy of the determinations.

General methods of testing are described, with a connection diagram and an outline of the necessary precautions. The detail procedure for tests for different losses is given.

It is shown how this method of test furnishes data for the separation of the friction from the windage. The division of mechanical losses between generator and turbine in a specific case is also described.

The procedure in determining the electrical losses from the test data is given and some observations made regarding the apparent desirability of the further refinement of the method.

While the retardation method of determining generator losses has long been known and is recognized by the Institute Standards, the Institute records are peculiarly lacking in literature on the subject, a search of the Index having failed to disclose a single paper on, or specific reference to, retardation tests. It seems rather strange that a method of testing which has found its way into the Institute Standards should have received so little attention in its literature. The explanation probably lies in the inherent simplicity of the method and the comparative rarity of its use in past times. It would appear that the method has been, and is yet, considered as a "last resort" method, to be used only when no other method is possible. It is the writer's purpose to show that the method has advantages and virtues of its own, not possessed by the usual and better known methods. It has, in the writer's opinion, never received the attention or publicity it deserves, nor been subjected to the intensive study for the perfection of its technique that is warranted by its possible accuracy and its ease of application.

The writer's attention has been focussed upon this method by the necessity of determining the conventional efficiencies of a considerable number of large water-wheel driven generators. The usual or standard method of determining generator losses is by driving the generator with a motor of known efficiency, and measuring the input to the motor under the various desired conditions. This method is usually impracticable in the case of large water-wheel generators. The most practicable and available method of making loss tests on such installations is by means of the retardation method.

The lack of repute which has apparently been attached to this method is probably due to two factors: first, that it depends upon the fly-wheel effect, $W R^2$, of the rotating parts, the determination of which has been considered to lack accuracy since it has been assumed that this value had to be calculated from the design: second, that the accurate measurement of speed and time are attended with certain difficulties which require the use of more refined methods and instruments than the usual stop-watch and indicating tachometer.

As a matter of fact, the fly-wheel effect can be determined by test; and the rate of retardation can be determined by automatic recording devices far more accurately than by the tachometer and stop-watch. In fact, the method lends itself naturally to automatic graphic recording methods, which may be made of almost any degree of accuracy desired.

This paper, therefore, will describe the procedure followed in the determination of the losses in the large generators of the Niagara Falls Power Company in an attempt to demonstrate thereby the practicability of the retardation method for the determination of the losses in such units.

The Retardation Method of Loss Test. The retardation method is based upon the fundamental law for the kinetic energy of a rotating mass, *i. e.*:

$$E = 1/2 \frac{W R^2 \omega^2}{g} \tag{1}$$

Where E is the energy.

$\frac{W}{g}$ is the mass of the rotating body

R is the radius of gyration, and

ω is the angular velocity.

If energy is added, the angular velocity or speed of rotation must increase, and if energy is abstracted, the speed must decrease. Obviously the rate at which the speed decreases must be a function of the rate of abstraction of energy, that is, of the power loss, and will be given mathematically by the first differential of

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equation (**1**) with respect to time. The equation for power loss then takes the form:

$$\frac{d\,E}{d\,t} = \frac{W\,R^2 \,.\, 2\,\omega\,d\,\omega}{2\,g \quad d\,t} \tag{2}$$

Putting $\omega = 2\,\pi\,s$ (where s is speed rev. per sec.)

$$\frac{d\,E}{d\,t} = \frac{W\,R^2}{2\,g} \,.\, 8\,\pi^2\,s \,.\, \frac{d\,s}{d\,t} \tag{3}$$

Expressing this equation in convenient units for the purpose of generator-loss measurements, we have:

$$\text{Loss in kw.} = \frac{4\,W\,R^2\,\pi^2\,S}{32.2\,(3600 \times 33000 \times 1.34)} \cdot \frac{d\,s}{d\,t} \tag{4}$$

Where

W is weight in pounds

R is radius of gyration in ft.

S is rev. per min.

$\frac{d\,s}{d\,t}$ is rate of retardation in rev. per min. per min.

32.2 is the acceleration of gravity in ft. per sec. per sec. and the expression in parenthesis in the denominator contains the necessary conversion factors to convert from sec. to min. and from ft-lb. per sec. to kw.

Assuming $W\,R^2$, the "fly-wheel effect," to be known it is then only necessary to determine the speed (S) and the corresponding simultaneous value of the rate of retardation $\left(\frac{d\,s}{d\,t}\right)$ to determine the corresponding instantaneous value of power loss.

For convenience it is desirable, for each generator tested, to combine all of the constants into a single constant which may be called the "retardation loss coefficient" and which may be designated by the letter D. The loss in kw. for that particular generator will then be:

$$\text{Loss in kw.} = D\,S\,\frac{d\,s}{d\,t} \tag{5}$$

Determination of $W\,R^2$. The usual method of determining $W\,R^2$ is by calculation from design, or from design corrected by actual measurement of weights. This is a rather laborious process, but one which can, if necessary, be carried out to almost any desired degree of accuracy. The usual method is to divide the mass up into simple forms, the weights and radii of gyration of which can be easily calculated, the summation of all the parts giving the desired value for the whole. The generator manufacturers are usually required to state this value for use in the governor design, and it is therefore usually available.

The value of $W\,R^2$ can, however, be determined by means of a retardation test in connection with the direct measurement of the friction, windage and iron loss by input. In this test the generator is driven as a synchronous motor by a second generator connected to its terminals. Readings of input to the driven machine are made, also of the corresponding values of current, voltage and speed. From these readings, the values of combined friction windage and iron losses are determined. Upon the completion of these tests, the driving generator is disconnected, after raising the speed slightly, and a retardation test carried out while values of voltage, speed and rate of retardation are carefully obtained. By substituting in formula (**4**) above, the corresponding values of loss, speed and rate of retardation obtained from these two tests, the value of $W\,R^2$ can be readily calculated. It will usually be found, if the work is carefully performed, that the value of $W\,R^2$ so found, will check very closely with that obtained by calculation from design.

Determination of speed (S) *and rate of retardation* $\left(\frac{d\,s}{d\,t}\right)$. In the earlier tests, these quantities were measured by means of the tachometer and stop-watch, but it was found by experience that such methods are apt to give inaccurate results, particularly at the higher speeds where the speed is most rapidly changing, due to the inaccuracies of tachometers and the difficulty of accurate timing by such means.

In the later tests, automatic means were employed for recording graphically the quantities from which the speed and rate of retardation are deduced. These means comprised three devices, namely:

1. A contact-making revolution counter
2. A contact-making timer
3. A two-element chronograph

The revolution counter consisted merely in a train of gears arranged to be driven directly by the rotor of the generator under test, and with a contact-making device arranged to make contact every 10 revolutions of the generator. Any other number of revolutions per contact could, of course, be chosen if desired.

The timer used in these tests was one driven by a clock and arranged to make contact once every five sec. omitting a contact once every minute. Any other time interval within reasonable limits could likewise be provided by suitable means.

The chronograph used in these tests was a rather crude device in which the paper used for record was wrapped about a cylinder and glued to make a continuous cylinder of paper. The two pens were mounted upon the armatures of two small solenoids, so arranged that upon making circuit through the coils the pen is moved a millimeter or two, parallel to the axis of the cylinder, returning to its original position upon breaking the circuit. The cylinder is mounted upon a coarse screw thread and driven by a small synchronous motor, and advances along its axis one in. (25.4 mm.) with each revolution which it makes. In the tests to be described, the paper was driven at a speed of about three in. (75 mm.) per min. Experience has shown, however, that

a greater speed would be preferable in order to give greater accuracy in determining the generator speed.

Fig. 1 shows, *a* Timer, *b* Chronograph, and *c* Revolution Counter. The chronograph shown is not the one used in the tests herein described, but one built for future use. Fig. 2 is a reproduction of a typical chronograph record of a retardation test.

Interpretation of Chronograph Records. By drawing straight lines across the record at suitable equal time intervals, the number of revolutions occurring in each

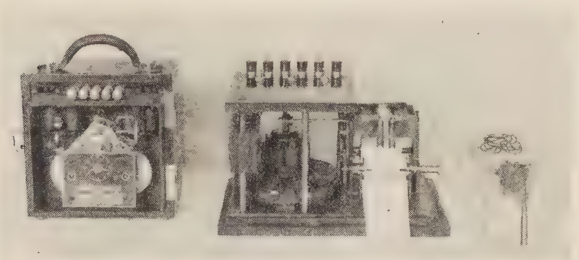

FIG. 1—THE CHRONOGRAPH BY WHICH TESTS WERE MADE

a. Timer
b. Chronograph
c. Revolution counter

of such time intervals can be accurately measured, thereby determining the average speed of rotation during each such interval. Tabulating these and taking the differences between successive readings, gives the average rate of retardation occurring between such successive speeds. If the time intervals are taken sufficiently short the average speeds for each interval can, with sufficient accuracy, be taken as occurring at the middle of the intervals, and the corresponding values of $\frac{d\,s}{d\,t}$ as simultaneous with the times dividing the intervals. Also the speed at the division points can with sufficient accuracy be taken as the average of the preceding and succeeding intervals. In illustration, the following tabulation, Table I, is from the chronograph record of a test for friction, windage and iron loss, on a 65,000-kv-a. generator.

The curve shown in Fig. 3 is a plot of these losses against speed, from which the desired value at normal speed can be read. These results are quite consistent, and no great error can be made by this method, since errors in one direction in one or more readings must be compensated by errors in the other direction in succeeding ones. Hence, the individual errors can confidently be eliminated by plotting the results graphically.

TABLE I

FRICTION, WINDAGE AND IRON LOSS BY RETARDATION

Time Minutes	Av. rev. per min.	(S) Rev. per min.	$d\,s/d\,t$ Rev. per min. per min.	Kw. (0.525 S $d\,s/d\,t$)	Remarks
0					
	17.6				
1		111.00	13.2	769	These values of kw. are obtained by using the value of $W\,R^2$ as calculated from design, *i. e.*, 68,255,000 lb.-ft. (Retardation loss coefficient = 0.525)
	104.4				
2		98.40	12.0	620	
	92.4				
3		87.35	10.1	463	
	82.3				
4		77.85	8.9	363	
	73.4				
5		69.35	8.1	295	
	65.3				
6		61.60	7.4	239	
	57.9				
7		54.70	6.4	184	
	51.5				

In the usual application of the retardation method, as set forth in the handbooks, its has been customary to determine $d\,s/d\,t$, the slope of the retardation curve, at normal speed only. This has resulted in a lack of accuracy and is undoubtedly in part responsible for the lack of confidence in the method. By the method of determination here set forth, this inaccuracy is eliminated by the device of using the entire curve to eliminate the errors in individual points, which is particularly applicable in this case since the curve as a whole cannot depart far from the truth.

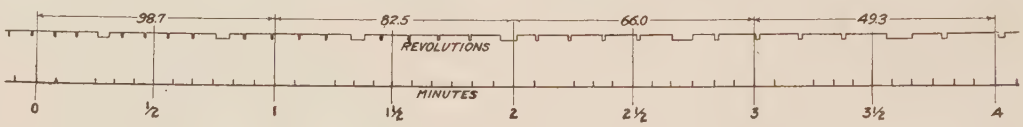

FIG. 2—CHRONOGRAPHIC RECORD OF RETARDATION TEST FOR FRICTION, WINDAGE AND LOAD LOSSES ON 65,000-KV-A. GENERATOR

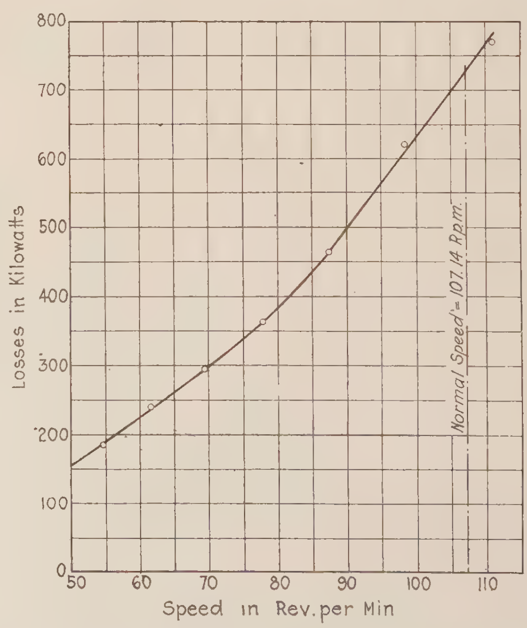

FIG. 3—FRICTION, WINDAGE AND IRON LOSSES OF 65,000-KV-A. UNIT WITH EXCITATION CORRESPONDING TO 11,100 VOLTS AT 107.14 REV. PER MIN.

This same test will illustrate the method, mentioned above, of determining by test the value of $W R^2$. The same machine showed friction, windage and iron losses as measured by input, at normal speed of 107.14 rev. per min., and at the same voltage as obtained at normal speed during the retardation test of 695 kw., see Fig. 4. The value of $d s/d t$ at the same speed, from the retardation test is 12.99 rev. per min. per min. Therefore, from equation 4:

$$W R^2 = \frac{695 \times 36000 \times 33000 \times 1.34 \times 32.2}{4 \times 9.87 \times 107.14 \times 12.99}$$

$$= 64{,}700{,}000$$

$W R^2$ as calculated from design	68,255,000
Difference	3,555,000

or about 5 per cent. Much closer agreement than this

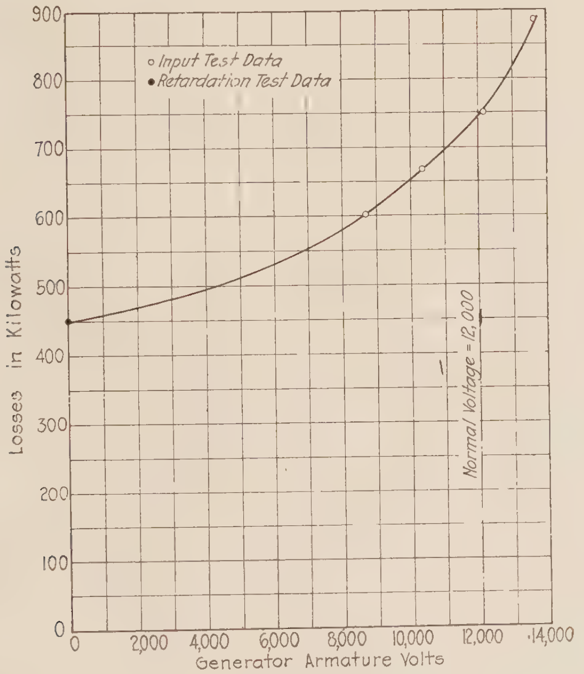

Fig. 4—Friction, Windage and Iron Losses of 65,000-Kv-a. Unit—Normal Speed 107.14 Rev. per Min.

is usually found, in many cases the test value checking exactly with the calculated, see Fig. 6. However, in a machine of this size, even an error of this magnitude could only affect the efficiency determination by less than one-tenth of one per cent.

General Methods of Test. Before starting a series of retardation tests, it is necessary that the unit be properly prepared. It is desirable that the generator be separated from the turbine, if possible. In horizontal-shaft units and in vertical-shaft units where the generator has a lower guide bearing, the coupling can usually be separated and the generator operated without the turbine. In vertical units where the generator has no lower guide bearing, or where, for some other reason, the coupling cannot be separated, it becomes necessary to permit the turbine to rotate with the generator. This introduces losses which cannot be charged to the generator and considerable judgment and ingenuity is then required to apportion the observed losses between generator and turbine.

When it is necessary to include the turbine rotor with the generator, precaution should be taken to guard against injury to the turbine by overheating bearings or glands or runner rim by possible rubbing at the

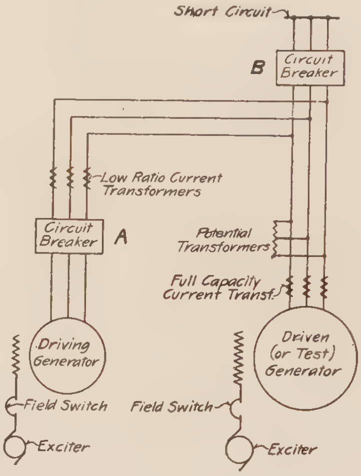

Fig. 5—Diagram of Connections for Retardation Tests

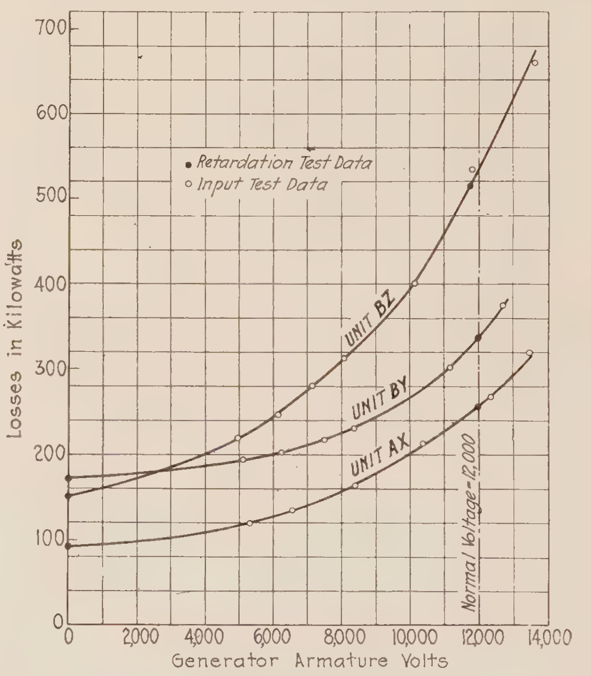

Fig. 6—Friction, Windage and Iron Losses of Three 32,500-Kv-a. Units—Normal Speed 150 Rev. per Min.

latter point, due to too close clearance. A small amount of water can usually be supplied to such points to keep them cool. In such a case, however, it is essential that conditions of water flow, etc., be kept constant during the tests in order to eliminate any variable factors from this source.

The simplest and most practical method of bringing the generator up to speed is to drive it as a motor from

another generator of the same voltage. The driving generator can be of considerably smaller capacity than the one to be driven, no difficulty whatever having been experienced with a ratio of ratings of one to four. The driving and driven machines are synchronized from rest in a manner now well understood. Fig. 5 shows the connections as usually employed for all tests.

In the leads from the driving machine there should be an oil circuit breaker, and current transformers. For the latter, a primary ampere capacity of about 6 per cent of the rated current of the driven machine, with 5-ampere secondary, has been found satisfactory. Such a size is large enough to carry the current required to accelerate the driven machine (if not accelerated too rapidly), and is small enough to give good readings on standard 2.5- to 5-ampere ammeters and wattmeters when measuring the input to the driven machine. In any specific case the required size should be calculated from the estimated friction, windage and iron losses. Suitable means should also be provided for measuring voltage and power input. It is assumed that proper calibrations of all instruments and instrument transformers will be taken care of in the standard manner.

It is preferable that the machine under test be separately excited in order to eliminate complications. However, if a direct-connected exciter is used, allowance must, of course, be made for the output and losses thereof.

Procedure. It has been found most convenient to make tests in the following order:

1. Friction, windage and iron loss by input
2. Friction, windage and iron loss (or $W R^2$) by retardation
3. Friction and windage by retardation
4. Friction and windage and load loss by retardation

1. Friction, Windage and Iron Loss by Input.

Close fields of both machines and circuit breaker A (leaving B open,) Fig. 5, and synchronize from rest. Bring machines up to normal speed gradually so as not to dangerously overload current transformers. Raise voltage to 10 or 15 per cent above normal for first reading. Take readings of voltage, current, power input, field current and speed at successive voltages down as low as field controls will permit. Usually readings can be carried down to about half voltage. Take at least 10 readings at each point at 15 sec. intervals. Before each series of readings see that field current of driving machine is adjusted so that armature current is a minimum, with driven machine field adjusted for desired voltage.

2. Friction, Windage and Iron Loss by Retardation.

At completion of input test, as above, raise speed to about 15 to 20 per cent above normal, adjust field current for normal open circuit voltage at normal speed, as per saturation curve, and open circuit breaker A, Fig. 5. As speed decreases record revolutions and time by means of chronograph as described above. Read volts, field current and speed by tachometer, (for check only, if a reliable one is available) at time intervals synchronized with chronograph. Field current should remain constant throughout test. Records should continue until speed has decreased at least to half normal value.

This test can be repeated for as many values of field current or generator voltage as desired. However, a single test at rated voltage will usually be sufficient to check the input test and the value of $W R^2$. Should a good check not be obtained, however, it is desirable to repeat and correct the value of $W R^2$ if the value calculated from design appears to be persistently in error.

3. Friction and Windage by Retardation.

Synchronize from rest and bring to 15 or 20 per cent above normal speed. Open oil circuit breaker between machines and immediately open field switch of test machine. As speed decreases, record revolutions and time on chronograph and read speed on tachometer (if available) at times synchronizing with chronograph record. Record should be continued to well below half speed in order to obtain as much of this curve as possible for a purpose to be explained later. A single test should be sufficient to determine friction and windage.

4. Friction, Windage and Load Losses by Retardation.

With circuit-breaker B open, close circuit breaker A and synchronize from rest as usual. Raise speed to above normal as before. Quickly open circuit-breaker A, open field switch, close circuit-breaker B, close field switch and quickly adjust field current to give desired armature current as per closed circuit saturation curve. These operations can and should be completed before speed has come down to 10 per cent above normal, in order that steady conditions may exist while speed is passing through normal value. Record revolutions and time by chronograph, and make synchronized readings of speed and of field and armature currents. This test should be repeated at various armature currents in order to obtain data for a curve of stray-load loss versus armature current.

Separation and Determination of Friction and Windage. The nature of the friction and windage losses and the consequent laws governing the form of the friction and windage retardation curve furnish a means of separating the "apparent friction" from the "apparent windage" losses.

With a constant coefficient of friction, the friction loss should vary directly as the first power of the speed.

The windage loss, however, in accordance with the well-known laws governing the movement of air, should vary directly as the third power of the speed. It would seem, therefore, that the curve of windage and friction losses against speed, should have the form:

Total friction and windage loss $= F S + W S^3$ **(6)**

Where F may be called the coefficient of friction loss and W the coefficient of windage loss, S being the speed in rev. per min.

Upon plotting such a curve from the record of a fric-

tion and windage retardation test, it is found to conform exactly to this law.

TABLE II
FRICTION AND WINDAGE BY RETARDATION

Time Minutes	Av. rev. per min.	(S) Rev. per min.	(d s/d t) Rev. per min. per min.	Loss kw.	Remarks
0					
	115.4				
1		111.25	8.3	485	
	107.1				
2		103.20	7.8	423	
	99.3				
3		96.25	6.1	309	$W R^2$ (from design) 68,255,000 lb.-ft.^{2} (Retardation loss coefficient = 0.525)
	93.2				
4		90.20	6.0	285	
	87.2				
5		85.50	5.4	240	
	81.8				
6		79.30	5.0	209	
	76.8				
7		74.65	4.3	169	
	72.5				
8		70.55	3.9	145	
	68.6				
9		66.75	3.7	130	
	64.9				
10		63.05	3.7	123	
	61.2				
11		59.95	2.5	78.7	
	58.7				
12		57.00	2.8	84.0	
	55.6				
13		54.45	2.3	66.0	
	53.3				
14		52.15	2.3	63	
	51.0				
15		49.85	2.3	60.2	
	48.7				
16		47.60	2.2	55	
	46.5				
17		45.60	1.8	42.2	
	44.7				
18		43.75	1.9	43 6	
	42.8				
19		42 05	1.5	33.1	
	41.3				
20		40.35	1.9	40.1	
	39.4				

Table II is the data from the graphic record of such a test, and Fig. 7 shows the values plotted from Table II.

The coefficients are readily found by substituting in equation (**6**) the values of total loss and speed for two points of the curve and solving simultaneously. For example, taking the values at 100 and 60 rev. per min. from a trial curve drawn for the test points of Fig. 7 and substituting in equation (**6**) we have the simultaneous equations:

$$372 = 100\,F + 1{,}000{,}000\,W$$

$$94 = 60\,F + 216{,}000\,W$$

Solving for F and W we have:

$$F = 0.355$$

$$W = 0.0003365$$

Recalculating for successive values of S, we have:

TABLE III
FRICTION AND WINDAGE LOSSES BY CALCULATION EQUATION (**6**)

(S) Rev. Per Min.	Friction Loss in Kw.	Windage Loss in Kw.	Total Loss in Kw.
40	14.2	21.6	35.8
50	17.7	42.0	59.7
60	21.3	72.7	94.0
70	24.9	115.5	140.4
80	28.4	172.0	200.4
90	31.9	245.0	276.9
100	35.5	336.5	372.0
110	39.1	347.0	486.1
120	42.6	581.0	623.6

Plotting these values we find the resulting curve, Fig. 7, to correspond with the test values with practical exactness at all speeds. This curve is quite sensitive to small changes in the values of the coefficients of friction and windage losses, and several trials are sometimes necessary before the correct coefficients are found to make the curve fit the test points at all parts of the

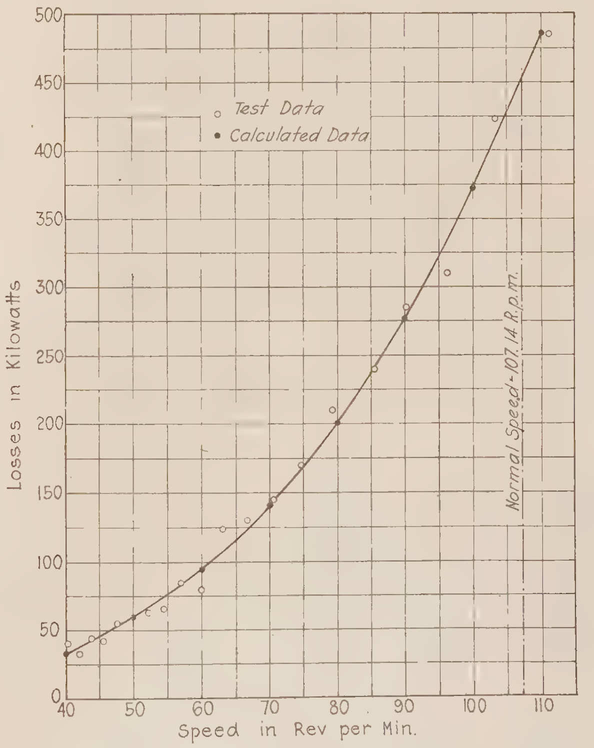

Fig. 7—Friction and Windage Losses of 65,000-Kv-a. Generator

curve. When this has been done, however, one can be quite confident that the resulting values of total losses are correct, whatever the separate values of "apparent friction" and "apparent windage" may represent, see Fig. 8.

It is indeed probable that even in the case of a test upon a generator alone, separated from its turbine, the "apparent friction" loss may include some of the windage and the "apparent windage" some of the bearing friction, since it seems probable that a small part of the

bearing losses are of such a nature as to vary with the third power of the speed. However, while there may be some doubt as to the exact composition of the two kinds of losses differentiated in this manner, their separation is nevertheless well worth while for the purpose (if for no other) of detecting the presence of any possible abnormal friction loss, such as a tight bearing or gland, or a rubbing turbine seal, which would surely show up in an abnormally large first power loss.

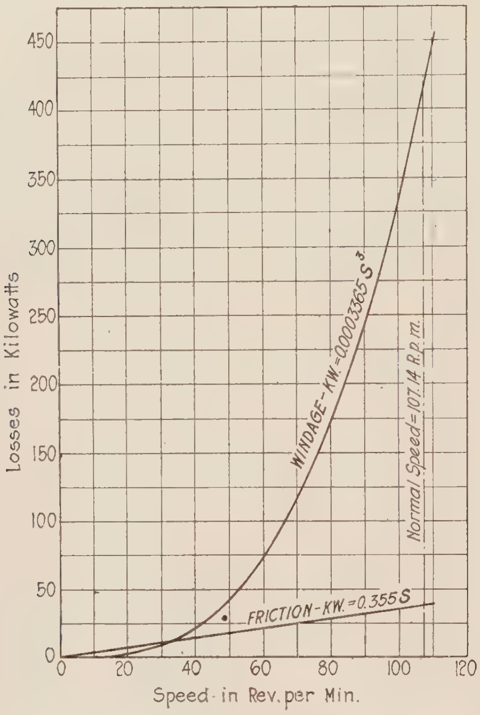

Fig. 8—Friction and Windage Losses of 65,000-Kv-a. Generator

However, the author believes, from experience in testing several different types and makes of generators by the above methods, that the separate "apparent friction" and "apparent windage" found by this method are very close to the actual friction and windage losses, when not complicated by other factors such as "disk friction" or "pumpage" losses in the turbine, due to the presence of water for cooling purposes.

Division of Friction and Windage Between Generator and Turbine. In those cases where tests are made with the turbine connected, the friction losses as above determined, will include turbine friction in bearings, glands and seals, and the "apparent windage" loss will include windage in the turbine and probably another loss due to the presence of a small amount of water in the turbine, which may be classed as "disk friction" or "pumpage." These losses can, at present, only be approximated, but by separating the first and third power losses by the method described above, these approximations can be handled with much more confidence than when the mechanical losses are all lumped together.

In an isolated case of a single unit, the division of the mechanical losses between generator and turbine is quite difficult, if not impossible. In a case, however, where several units of similar but different characteristics are being tested, it is often possible, by careful observations and comparisons, to make approximations which give results approaching the truth closely enough for practical purposes.

As an illustration of what may be done along this line, the steps taken in allocating the mechanical losses in three units of 32,500-kv-a. capacity, comprising three different combinations of turbines and generators will be described. If we designate the two turbine manufacturers by the letters A and B, and the three generator manufacturers by X, Y and Z, then we can designate the three units as $A\ X$, $B\ Y$ and $B\ Z$.

The friction and windage losses of these three machines, all of the same capacity rating, and the steps by which they were allocated, are shown in the following tabulation:

TABLE IV

ANALYSIS OF FRICTION AND WINDAGE OF THREE 32,500-KV-A. UNITS

	Unit $A\ X$	Unit $B\ Y$	Unit $B\ Z$
Total Friction, Windage & Pumpage.......	91.65	171.5	151.05
Friction.............................. H	18.75	28.0	28.25
Windage and Pumpage..................	72.90	143.5	122.80
Analysis of Friction			
Weight of Generator Rotor and Shaft..... A	271,000	311,000	318,000
Weight of Turbine Runner and Shaft..... B	73,500	73,500	73,500
Weight on Thrust Bearing during Test.... C	344,500	384,500	391,500
Hydraulic Thrust......................	100,000	100,000	100,000
Weight on Thrust Bearing under Load.... D	444,500	484,500	491,500
Thrust Friction under Load $\left(\frac{D}{444500}\times 15\right)$ E	15.0 kw.	16.35kw.	16.6 kw.
Thrust Friction during Test $\left(\frac{C}{D}\times E\right)$ F	11.62	12.95	13.25
Generator Share of F $\left(\frac{A}{C}\times F\right)$...... G	9.15	10.46	10.76
Turbine Share of F $\left(\frac{B}{C}\times F\right)$........	2.47	2.49	2.49
Total Friction from retardation test ...... H	18.75	28.0	28.25
Total Thrust Bearing Friction during test. . F	11.62	12.95	13.25
Other Friction, guide bearings, etc., $(H-F)$ I	7.13	15.05	15.00
Generator Share of I .... J	2.0	2.0	2.0
Turbine Share of I..........................	5.13	13.05	13.0
Total Generator Friction $(G+J)$..........	11.15	12.46	12.76
Analysis of Windage & Pumpage			
Total Windage and Pumpage (Ret. Test)...	72.9	143.5	122.8
Generator Windage (Est.)................	50.0	93.5	72.8
Turbine Windage (Est.)..................	10.0	10.0	10.0
Turbine Pumpage (Est.)..................	12.9	40.0	40.0
Total Generator Friction & Windage......	61.15	105.96	85.56

That portion of the loss which is proportional to the third power of the speed was at first thought to be entirely windage, but upon further investigation it was found that there might be a loss in the turbine of the nature generally called disk friction which also varies as the third power of the speed, and, owing to the different construction of the two types of tubine, it is reasonable to expect that under test conditions these losses might differ very markedly between the two types. This

presumption is further corroborated by the very great discrepancy between the measured so-called windage losses of *A X* and *B Y* and *B Z*, these losses in the case of *B Y* being just about double the corresponding losses of *A X*, see Fig. 6. It hardly seems reasonable to charge this discrepancy entirely to true windage.

The same sort of reasoning applies also to the friction losses. The thrust and guide bearings of the three units do not differ materially, but there is a considerable difference in the nature and area of the turbine seals between the *A* and *B* designs, and it would, therefore, seem reasonable to expect that that portion of the friction loss which takes place in the seals would be somewhat in proportion to the areas of the contiguous surfaces.

Analysis of Friction Loss. At the time when Unit *A X* was placed in service, the bearing manufacturer's engineers made a determination of the loss in the thrust bearing of this unit and stated that this loss was apparently about 20 h. p., or 15 kw. This value has been used as a basis for the analysis of the friction loss, it being assumed that the loss in these thrust bearings will vary in direct proportion to the weight that they carry. This loss has also been further divided between the generator and turbine in proportion to their weights.

Upon subtracting the value thus determined for the thrust bearing on Unit *A X* from the total friction losses as determined by test, there remains but slightly over seven kw. to be divided between the generator and turbine-guide bearings and turbine seals. In consideration of the smallness of this loss, the nature of the parts which create it, and the relation which might be expected to exist between the generator guide and thrust-bearing losses, it was concluded that two kw. would be a reasonable portion of this loss to assign to the generator-guide bearings, the remainder being charged to the turbine.

In the case of the other two units, the total measured friction losses were considerably greater and the thrust-bearing friction was also somewhat greater, due to the increased weights of these machines over that of Unit *A X*. There appeared, however, no reason why the guide-bearing loss should be any greater than on Unit *A X*, and the assumption checks with the observed fact that the guide-bearing oil temperatures of the three units do not materially differ from each other.

There is then left chargeable to turbine friction approximately 13 kw. in Units *B Y* and *B Z*, or about two and one-half times the corresponding loss in Unit *A X*, which ratio would appear reasonable from a consideration of the two turbine designs. This results in the friction losses of the three generators differing by only such amounts as are accounted for by their different weights.

Analysis of "Windage" Loss. In the case of the so-called windage losses—all those losses varying as the third power of the speed—the total of such losses in the case of Unit *A X* was but 72.9 kw. As stated above there is too great a discrepancy between this value and those of similar losses determined for the other two units to be all charged to generator windage, and it is accordingly necessary to find some other difference between the two turbine designs to account for a part of this discrepancy. The value of this loss is about 20 kw. greater for Unit *B Y* than for Unit *B Z*. This difference is believed to be reasonably accounted for by the fact that in Unit *B Y* a large volume of air was allowed to discharge around the end windings of the armature, no attempt having been made to limit the discharge at these points to merely that necessary to maintain the temperature within safe limits, whereas, in the case of Unit *B Z* the corresponding openings have been partially blocked for this purpose. The additional air moved in the case of Unit *B Y* might account for the 20-kw. difference.

There then remains a difference of approximately 50 kw. between these losses on Units *A X* and *B Z*. Part of this difference is undoubtedly in the generator and a part in the turbine. The designer of the Generator *X* was particularly careful to decrease to the greatest possible extent the windage loss by careful fan design and by the addition of sheet-metal shrouds on the generator-rotor spider and fan for the purpose of directing the air currents, while apparently such provisions are not carried out to the same extent in the case of Generator *Z*.

As to the turbines, an inspection of the respective runner designs indicates that in the case of Turbine *B* the lubricating water from the lignum-vitae bearing is much more apt to get away through the upper seals of the turbine than is the case of Turbine *A*, and this might readily account for a considerable part of the observed difference in losses.

A formula was given in the water-wheel test code for determining the turbine windage, but in this case this formula gave a value of approximately 50 kw., which, in the case of Unit *A X* is obviously far too high, as it would leave but about 23 kw. for generator windage. There is, however, undoubtedly some windage loss in the turbines under test conditions, and this was approximated by reference to fan data. It was found that the shut-off power of a fan was in the neighborhood of 20 per cent of the full-load power, and it was assumed that the 50 kw. resulting from the above mentioned formula would represent the full-load power of the turbine runner as a fan, which appeared reasonable from a consideration of its dimensions and in comparison with fan data. It was then assumed that the shut-off power or windage with turbine gates closed would be 20 per cent of this, or 10 kw. This was assumed to be the same for all three turbines. There was then left, in the case of Unit *A X*, 62.9 kw. to be divided between generator windage and turbine disk friction. Of this 50 kw. was arbitrarily charged to generator windage, as this seemed a reasonable value, and left an amount of 12.9 kw. chargeable to turbine disk friction. In the

case of Units B Y and B Z, it was thought that the disk friction might be approximately three times that of Unit A X, and was accordingly put at 40 kw., leaving for generator windage 93.5 kw. in the case of Unit B Y, and 72.8 kw. for Unit B Z, as compared with the 50 kw. assumed on Unit A X. The value of 50 kw. (40 + 10) for turbine windage and disk friction happens to be the same as would have been assigned to turbine windage had the test code formula been used, hence, should not be open to serious criticism.

The final values of generator friction and windage then become for Unit A X, 61.15 kw.; Unit B Y, 105.96 kw.; and Unit B Z, 85.56 kw. We have two checks on these figures; first, the designer of Generator Z stated that he estimated the friction and windage of his generator at 80 kw., and second, the designer of Generator Y, that of his at about 109 kw. We have a further check on the accuracy of the resulting values of generator efficiency in that the efficiencies of the turbines of Units B Y and B Z, based on the values of generator efficiency thus arrived at, checked each other exactly.

Separation and Determination of Electrical Losses

Iron Loss. Obviously the iron loss is determined by subtracting the friction and windage from the iron-loss

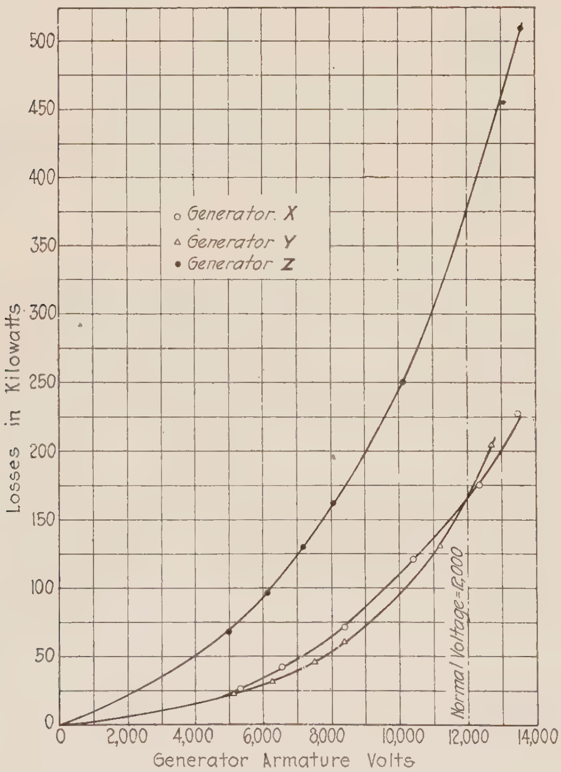

Fig. 9—Iron Losses of Three 32,500-Kv-a. Generators

friction and windage as determined either by the input or by the retardation test. Fig. 4 shows iron loss, friction and windage data for the 65,000-kv-a. unit, and Fig. 6 for the three 32,500-kv-a. units. The values of the friction and windage losses, of course, determine the termini of these curves on the zero voltage axis, thereby giving the necessary data for the completion of the lower part of the curves. Fig. 9 shows iron losses alone for the three 32,500-kv-a. generators and Fig. 10 for the 65,000-kv-a. generator.

Stray-Load Losses. Similarly the stray-load loss is

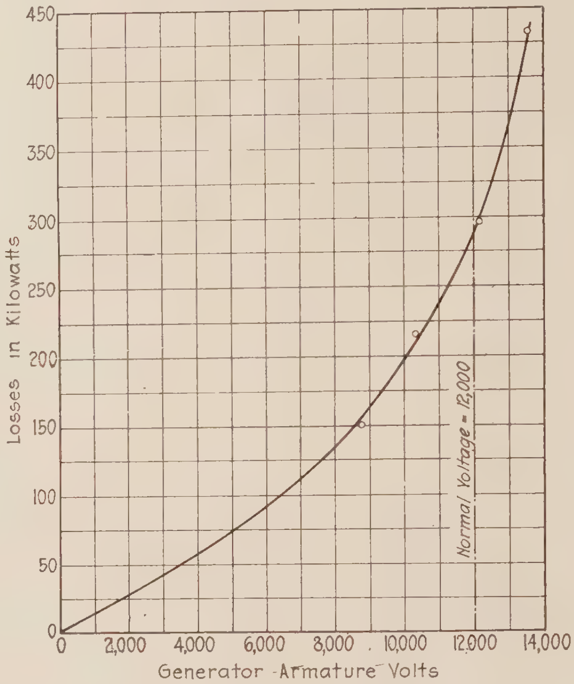

Fig. 10—Iron Losses of 65,000-Kv-a. Generator

determined by subtracting the friction and windage and armature $I^2 R$ loss from the appropriate test values. This has been done for the 65,000-kv-a. generator, the various steps by which the stray-load loss has been determined are indicated in Fig. 11.

Following the same general principles used in determining the friction and windage, and the iron loss, the test points are first determined and plotted for the delineation of a curve of loss against speed as obtained by the retardation test. In Fig. 11 these test points for armature currents of 1554 amperes, 2145 amperes, and 3156 amperes are shown respectively at a, b and c.

These points do not look very encouraging as almost any kind of a curve can, seemingly, be drawn through them. However, in delineating these curves, we are entitled to use all the information which we have, so, before drawing in the curves, it may be indicated on the sheet just what is known about the losses which are to be deducted. We, therefore, draw in the friction and windage loss curve, as per Fig. 7.

As to the $I^2 R$ loss, it is known both from theory and observation, that the short-circuit current remains practically constant at all speeds, hence, the $I^2 R$ loss is constant throughout the test. It is possible, therefore, to add a constant $I^2 R$ loss to the friction and windage-loss curve, obtaining the corresponding curves shown in Fig. 11.

The difference between this curve and the total-loss curve is the "stray-load" loss, and there should be some consistent relationship between the stray-load loss and speed. Three assumptions are possible:

1. Stray-load loss decreases as speed increases.
2. Stray-load loss constant as speed increases.
3. Stray-load loss increases as speed increases.

If the stray-load loss is caused mostly by eddy currents in the copper, as seems most likely, it would appear that it should increase with frequency, and the test points indicate in general that it does so. If so, three assumptions are again possible as to a possible

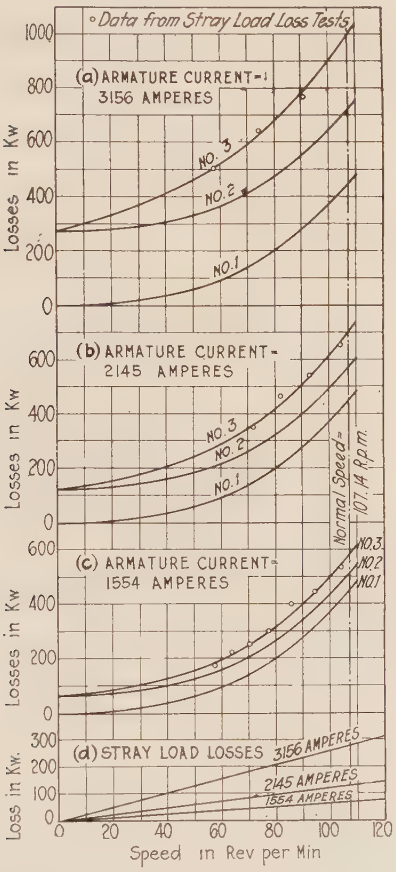

Fig. 11—Retardation Test for Stray Load Losses of 65,000-Kv-a. Generator

Curve No. 1—Friction and windage losses
No. 2—Curve No. 1 plus I^2 R losses
No. 3—Curve No. 2 plus stray load losses

exponent of the power of the speed by which it varies, that is, if it is assumed that:

$$\text{Stray-load loss} = C\, S^n \tag{7}$$

where C is a constant,
n may be

1. less than unity
2. equal to unity
3. greater than unity

In order to determine which of these assumptions most nearly agrees with the test data, trial curves were drawn and the speed-time curve reconstructed from points taken from the trial curves. The reconstructed curve based upon the assumption of $n = 1$ shows the better agreement, and this assumption was consequently used in drawing the final curve through the test points. The differences, however, between the results of the three assumptions are very slight, and none of them are probably scientifically true.

In drawing the curves, a point was selected on each of the trial curves through which it appeared the curve would have to pass whatever its form. From these values, the corresponding friction, windage and iron losses were deducted, the residual values being plotted on a rectangular scale and straight lines drawn through these points and the origin. These three lines, shown at *d* Fig. 11 are then the most probable curves of stray-load losses for different speeds at the three values of armature current. These three curves were then added to the friction, windage and $I^2 R$ loss curves to produce the total-loss curves as shown. It was found that the stray-load loss at any given speed varied almost exactly as the square of the current, the chance agreement of the trial points in this respect being so close that the final curves were intentionally so drawn.

These results would *seem* to indicate the following conclusions:

1. The short-circuit stray-load losses are due (at least mostly) to an increase in the effective resistance of the armature conductors, due, no doubt, to a displacement of the current in the conductors—usually called "eddy currents."
2. This increase in effective resistance varies with the speed or frequency, and appears to be substantially proportional to the first power thereof.
3. The increase in effective resistance is apparently independent of the armature current.

From these results, it would appear that, practically, the effective resistance of the armature would be expressed by the formula:

$$R_f = R\,(1 + K\,f) \tag{8}$$

where
R_f is resistance at frequency f
R is resistance for direct current
and
K is a constant.

While these conclusions *seem to be* indicated, it is, fo course, not safe to generalize from a single test, and further and more accurate determinations will be required to establish these relations definitely, if indeed, they actually exist at all.

However, in this case, it is apparently true that, for all practical purposes, the determination of the short-circuit stray-load loss for any current and any speed may be made from a single accurate test at one current and one speed. If formula (8), or one similar to it, should prove to be generally true, it would appear that some independent method of predetermining the coefficient (K) would be extremely useful.

Conclusions

1. The retardation method for determining certain of the losses in large generators is a useful, accurate, consistent and easily applied method, and deserves more extensive use and fuller official recognition.

2. The retardation method of measuring friction and windage losses contains within itself the means of separating these losses from each other. This is a very useful property when it is necessary to allocate such losses between the generator and its turbine. It is also useful for detecting abnormal friction or windage.

3. The determination of a loss at different speeds, which is a natural application of the retardation method, furnishes a means not only of more accurately determining such loss at normal speed, but also furnishes a means of throwing new light upon the nature of certain of the losses.

4. Development of apparatus and refinement of methods of carrying out retardation tests are desirable. An instrument to measure the rate of retardation directly, should be a possibility not difficult to realize.

Three Methods of Measuring Dielectric Power Loss and Power Factor

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Synopsis.—*The paper presents a brief description of the methods of measuring dielectric power loss and power factor in commercial use at the Electrical Testing Laboratories.*

The several methods are handled individually and their advantages and disadvantages listed.

Appendixes are included on the use of the shunted electrodynamometer as an ammeter, determination of compensation, effect of incorrect compensation in the wattmeter shunt, effect of slightly unbalanced voltages on three-phase measurements, a three-phase wattmeter switch and shielding, grounding, etc.

Introduction

The very fact that a symposium on methods of measuring dielectric power loss and power factor has been arranged is an indication that such measurements offer considerable difficulties, particularly when applied to present-day dielectrics. The purpose of this paper is to describe and discuss the methods now employed at the Electrical Testing Laboratories for such measurements.

Originality is not claimed for the methods described, but they have been improved and adapted as need for them has arisen. Experience has shown each to be satisfactory for the class of work for which it has been developed.

General

The three general methods to be described and the measurements for which they are adapted are as follows:

1. Compensated Wattmeter Method
   a. For single-phase measurements on cables
   b. For three-phase measurements on cables
2. Phase-Defect Compensation Method
   a. For high-voltage single-phase measurements on cables
   b. For single-phase measurements on low-voltage condensers of high capacitance
3. Transformer Bridge
   a. For single-phase measurements on very low capacitances (short pieces of cable, oils, compounds, sheet materials, etc.)

1a. The Compensated Wattmeter for Single-Phase Measurements.

This method consists in a direct measurement of the dielectric power loss in watts when an alternating potential is applied to the cable under test. As there is always a certain amount of "leakage" power in the test circuits and instruments, a measurement is first made of this "leakage" before the cable is connected for test. This "leakage" loss is then subtracted from the total loss with the cable or other dielectric in circuit in order to obtain the "net" or actual loss in the material under test.

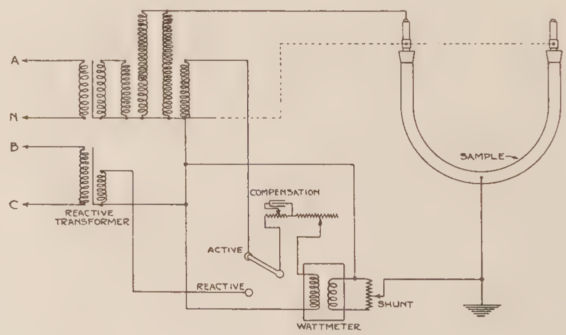

Fig. 1

This direct measurement is made using a shunted reflecting electrodynamometer wattmeter in connection with a potential transformer. The phase angle of the potential transformer and the self inductance of the

1. Both of Electrical Testing Laboratories, New York City.
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potential coil of the wattmeter are compensated for by the use of a shunted condenser of the proper value in the potential circuit of the wattmeter. The self inductance of the current element of the wattmeter is compensated for by the use of a shunted condenser in the wattmeter shunt. A diagram of the complete circuit used is shown in Fig. 1.

The equipment used in making such measurements is as follows:

1 Insulating transformer
1 Testing transformer
1 Voltage transformer
1 Reflecting electrodynamometer wattmeter
1 Compensated wattmeter shunt
1 Voltage-circuit resistance with compensation
1 Calibrating load
1 Lamp and scale
1 High-resistance voltmeter
1 Frequency meter
1 "Reactive" insulating transformer

When using this method the wattmeter is calibrated on low voltage against a resistance load. In this

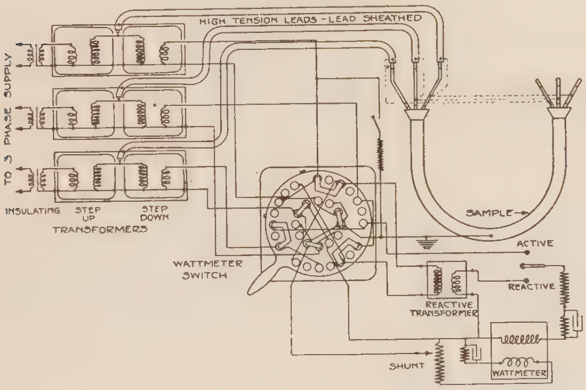

FIG. 2

operation the voltage circuit resistance is adjusted to give some even scale constant such as 0.001 watt loss in the high-voltage circuit per millimeter scale deflection.

After the calibration is completed the resistance in the compensation circuit is set for its correct value for the first test voltage. Since the burden on the potential transformer is practically constant from day to day, regardless of the sample under test, the value of compensating resistance necessary for various test voltages can be determined in advance by the methods described in Appendix II.

For speed in testing it is the usual practise to take a complete set of "leakage" readings covering the full range of test points and follow this immediately by "cable on" readings made at the same test voltages. These readings are referred to as "active" readings as distinguished from the "reactive" readings referred to below.

In order to determine power-factor it is then necessary to measure either the current, Appendix I, or the apparent power, reactive volt-amperes. It is the practise at these Laboratories to determine the reactive volt-amperes in this case rather than the current. With a three-phase, Y-connected supply and the test set operated on one phase, a transformer with a ratio of $\sqrt{3}$ to one connected across the remaining two phases furnishes a potential supply which makes it possible to read the reactive volt-amperes directly. In this case, as well as in the power readings, "leakage" readings and "cable on" readings are made for all test points. These readings are referred to as "reactive" readings.

A typical set of data is as follows:

	Active	Reactive
Voltmeter indication	20	
True voltage—kv	10	
Compensating resistance	249	
"Leakage" Measurements		
Dynamometer indication	−33	−67
Shunt	1	1
Total deflection	−33	−67
"Cable On" Measurements		
Dynamometer indication	112	168
Shunt	1	50
Total deflection	112	8400
Leakage deflection	−33	−67
Net deflection	145	8467
Net volt-amperes	0.145	8.467
Cotangent	0.0171	
Power factor, per cent	1.71	

The time required for an operator to take complete data on a test requiring six test voltages is about one-half hour. During this time he can make all computations as indicated in the sample data, these computations being made while waiting for the wattmeter to assume a steady deflection.

The sensitivity of this equipment is, of course, fixed in the calibration and remains constant throughout the test range.

The accuracy depends chiefly on the accuracy of compensation. With the present methods of determining compensation it is believed that an accuracy of ± 0.05 per cent in power factor should be obtained.

This type of equipment is sensitive to external conditions. The loss read by the wattmeter varies as the square of the applied voltage, so that small voltage variations multiply in their effect on the loss reading. The reactive volt-amperes vary directly as the frequency and as the voltage, hence these conditions must be constant and correct.

Dielectric power loss and power-factor measurements should be made using sine-wave potential. With this method, however, the power-loss is measured for the wave used, whatever its form may be.

Advantages:

1. Rapid operation—five minutes per test point including time for computations
2. Simple operation
3. Not affected by wave form of supply
4. High sensitivity

Disadvantages:

1. Accuracy of method depends on accuracy of compensation
2. Particularly susceptible to variations in supply voltage

1b. The Compensated Wattmeter for Three-Phase Measurements.

This method consists in a direct measurement of the dielectric loss in watts when a three-phase alternating voltage is applied to the sample of cable under investigation.

The method is essentially the three-wattmeter method for the determination of power in a three-phase, four-wire circuit. This method has been simplified by the use of one wattmeter in connection with a specially designed switch for connecting the wattmeter in each of the three circuits as desired. A complete diagram of this circuit is shown in Fig. 2.

The operation of this equipment is essentially the same as that described in Method 1a. Since it is very difficult to obtain balanced three-phase voltages, it has been found that best results are secured by holding the voltage constant on one phase, rather than trying to adjust to the correct voltage on each phase. The reasoning back of this is to maintain the conditions constant for each test point. When working on an unbalanced system this would not be true if the voltage were adjusted on each phase when the wattmeter is read.

The equipment used in making these tests is the same as that described in Method 1 *a*, except that three insulating, three testing and three potential transformers are required together with the special wattmeter switch, Appendix V.

A typical set of data from one of these tests is as follows:

Voltmeter indication.............	29
True line-kv....................	10
Compensating resistance.........	279

	Active	Reactive
"Leakage" Measurements		
Dynamometer Indication Ph. I...	−24	96
" " " II..	0	141
" " " III.	−52	120
" " Sum.......	−76	357
Shunt.........................	1	1
Total deflection................	−76	357
"Cable On" Measurements		
Dynamometer Indication Ph. I...	−36	87
" " " II..	107	81
" " " III.	−42	79
" " Sum.......	29	247
Shunt.........................	10	200
Total deflection................	290	49400
Leakage deflection..............	−76	+357
Net deflection..................	366	49043
Net volt-amperes................	0.366	49.043

Cotangent..............................	0.0075
Power factor, per cent...........	0.75

The advantages and disadvantages of this method are essentially the same as those described in Method 1a.

2a. Phase-defect Compensation Method for High-Voltage Measurements.

This method consists in a determination of the power factor or phase angle of the sample under test by a direct comparison of its apparent phase defect angle with that of a "no-loss" air condenser.

In this method a reflecting type electrodynamometer wattmeter, connected as for measuring watts loss, is made to read zero by changing the phase of the current in the potential circuit by inserting inductance of known value. Such a balance is obtained, first, against a "no-loss" air condenser, and then against the sample.

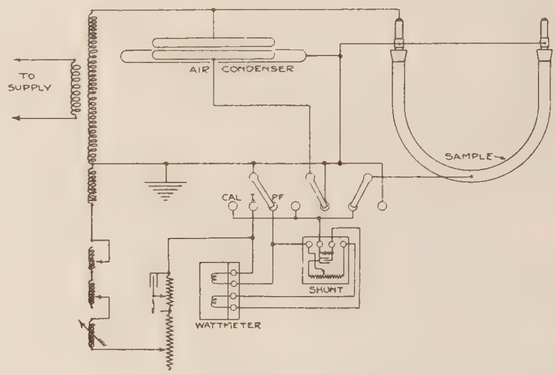

Fig. 3

From the difference in shift necessary the power factor or phase angle of the sample is obtained.

Complete connections used in this test are shown in Fig. 3.

The equipment used is as follows:

1 Testing transformer
1 Reflecting electrodynamometer wattmeter
1 Dynamometer shunt
1 Voltage circuit resistor with compensation
1 50- to 250-milhenry constant resistance tapped inductor
1 6- to 50-milhenry variable inductor
1 Lamp and scale
1 High-resistance voltmeter
1 Frequency meter
1 High-voltage variable air condenser, "no-loss"

In using this method the sample and the "no-loss" air condenser are kept connected to the transformer at all times in order to maintain the relative phase positions. For convenience in computing, the potential circuit resistance is kept constant at a value in ohms equal to 6 π times the frequency in cycles per second.

In order to determine the dielectric power loss the charging current is measured, using the electrodynamometer as an ammeter, Appendix I. Then from the charging current, the power factor and the test voltage, the dielectric power loss is computed.

A typical set of test data and computations is as follows:

Voltmeter indication	20
Test kv.	
Cable (Condenser Connected Directly to Ground)	10
Potential circuit resistance	1131
Observed Inductance—Direct	44.0
" " —Reverse	43.8
" " —Average	43.9
Ammeter shunt	5
Ammeter reading	452
True milliamperes	2.74
Condenser (Cable connected directly to ground)	
Observed inductance—Direct	35.0
" " —Reverse	35.6
" " —Average	35.3
Difference in inductance	8.6
Power factor of sample, per cent	0.29
Dielectric power loss, watts	0.079

To determine the constant of the ammeter the electrodynamometer is calibrated against a resistance load. This connection is obtained with the selector switch on "calibrate."

Fig. 4 is the vector diagram for this method where

E = Test voltage
I_a = Current to air condenser
I_s = Current to sample
E_p = Voltage applied to potential circuit
I_1 = Current in potential circuit when balanced against air condenser
I_2 = Current in potential circuit when balanced against sample
ϕ_1 = Apparent phase defect angle of air condenser
ϕ_2 = Apparent phase defect angle of sample

The computation of the power factor is based on the following theory. If L_1 is the inductance setting for

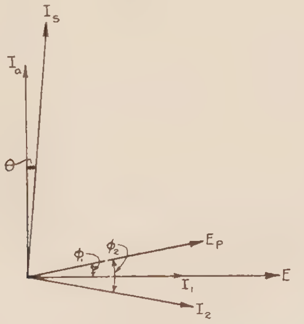

FIG. 4

zero reading on the air condenser, the phase shift of the current in the potential circuit in order to obtain the balance is

$$\tan \phi_1 = \frac{\omega L_1}{R} \tag{1}$$

Likewise, if L_2 is the inductance setting for balance against the sample, the phase shift of the current in the potential circuit is

$$\tan \phi_2 = \frac{\omega L_2}{R} \tag{2}$$

Since these are all small angles, the tangent is numerically approximately equal to the sine of the angle. Then, if θ is the phase-defect angle of the sample (difference between the actual angle and 90 deg.)

$$\sin \theta = \tan \phi_2 - \tan \phi_1 = \frac{\omega}{R} (L_2 - L_1) \tag{3}$$

or

$$\text{Power factor} = 100 \sin \theta = \frac{100\ \omega}{R} (L_2 - L_1) \tag{4}$$

But R has been made equal to 3 ω

Therefore,

$$\text{Power factor} = \frac{L_2 - L_1}{30} \tag{5}$$

when L_2 and L_1 are read in millihenries.

The computation of the power-factor is so simple that it is readily made while waiting for the ammeter to assume a steady deflection.

Computation of the charging current depends upon the ammeter connection used. See Appendix I for methods of using the electrodynamometer as an ammeter.

The time to take a set of readings covering six-test voltages is approximately one-half hour, during which time the power-factor values are also computed. The remainder of the computations may take as much as an additional 20 min.

The sensitivity of this equipment, when used for power-factor measurements, varies with the test voltage and the charging current to the sample under test. It is naturally more sensitive under higher currents and voltages.

When making the power-factor balance, voltage variations cause changing sensitivity, although at balance voltage variations have no effect (assuming no change in power factor with voltage). Likewise, frequency variations affect the sensitivity on power-factor measurements as well as change the apparent defect angle. On current measurements any variable causing a varying charging current (voltage or frequency) causes a variable reading, which is particularly objectionable since the deflection varies approximately as the square of the current.

The accuracy of this method is dependent chiefly upon the operator and upon the "no-loss" condenser. A careful operator should be able to make measurements to within $\pm$ 0.05 per cent power factor. The losses as computed from the current and power-factor should be well within $\pm$ 5 per cent accuracy.

In this equipment errors in wave form introduce an error in the power factor since it is computed on the basis of a sine wave. For harmonics which do not run above five per cent in value this is negligible.

Advantages:
1. Rapid operation
2. Simple operation

Disadvantages:
1. Variable sensitivity
2. Accuracy dependent on operator and on "no-loss" condenser
3. Frequency and voltage must be maintained constant

2b. Phase-Defect Compensation Method for Measurements on Low-Voltage Condensers of High Capacitance.

The measurement of losses in low-voltage condensers of high capacitance (such as are used for power-factor correction) may be accomplished by a modification of

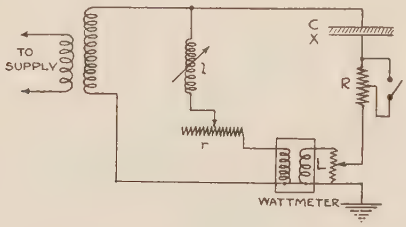

FIG. 5

Method 2a. The method then consists in a determination of the power factor of the test condenser by a comparison of the apparent phase-defect angles with different known values of resistance in series with it.

The diagram of connections is shown in Fig. 5. Here again a reflecting type electrodynamometer wattmeter is used, connected as for power measurement, and made to read zero by changing the phase of the current in the potential circuit by inserting inductance of known value. Such a balance is obtained for each of two or more known values of resistance in series with the test condenser.

In employing this method the following equipment is used:

1 Resistor having two or three steps
1 Reflecting electrodynamometer wattmeter
1 Lamp and scale
1 Variable inductometer
1 Voltage circuit resistor
1 Voltmeter
1 Frequency meter

Then, if

X = Series resistance of test condenser
C = Capacitance of test condenser
R = Resistance in condenser circuit (not including X)
L = Inductance of current circuit (usually that of current coil of wattmeter)
l = Total inductance of voltage circuit
r = Total resistance in voltage circuit
$\omega = 2\pi f$,

Fig. 6 shows that at balance

$$\frac{\omega l}{r} = \frac{X + R}{\dfrac{l}{\omega C} - \omega L} \qquad (6)$$

When l_1, r_1 and l_2, r_2 are the inductance and resistance values at balance corresponding to R_1 and R_2, respectively, the following equations can be deduced.

$$X = \frac{r_2 R_2 l_1 - r_1 R_1 l_2}{r_1 l_2 - r_2 l_1} \qquad (7)$$

$$C = \frac{l_1}{r_1 (R_1 + X) + \omega^2 L l_1} \text{ or } \frac{l_2}{r_2 (R_2 + X) + \omega^2 L l_2} \qquad (8)$$

If r_1 can be kept equal to r_2, equation (7) reduces to

$$X = \frac{R_2 l_1 - R_1 l_2}{l_2 - l_1} \qquad (9)$$

On the other hand, if a variable inductor is not available and r must be varied, equation (7) reduces to

$$X = \frac{r_2 R_2 - r_1 R_1}{r_1 - r_2} \qquad (10)$$

This latter arrangement produces one peculiar condition in that the sensitivity of the meter may change more rapidly than the phase angle of the potential circuit thus causing the electrodynamometer indication to

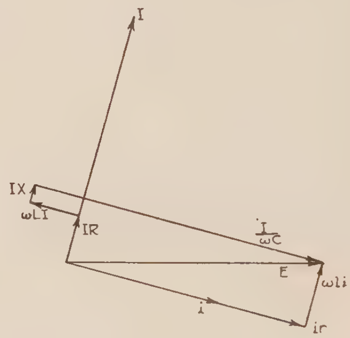

FIG. 6

become greater for a time as the balance point is approached.

A typical set of observed data and calculated results are shown below:

Test voltage, volts		440	
Frequency, cycles per sec		60	
Current-coil inductance, henrys		0.008	
Voltage-coil resistance, ohms		8000	
Resistance of current coil and leads, ohms		18	
"Test" resistance in current circuit, ohms	0		10
Total resistance in current circuit, ohms	18		28
Inductance of voltage circuit, millihenrys	400		588
Series resistance of test condenser, ohms		3.3	
Capacitance of test condenser, μ f		22.6	
Power-factor test condenser, per cent		2.81	
Loss in test condenser, watts		46.3	

Advantages:
1. No standard condenser needed
2. Settings only indirectly affected by frequency

Disadvantages:
1. Sensitivity variable
2. Constants of circuits must be known accurately

3a. The Transformer Bridge.

By this method the capacitance and equivalent shunting resistance are determined by comparison of the test sample with a "no-loss" air condenser. Each is inserted separately in one circuit of the bridge while the other circuit of the bridge containing known capacitances and resistances is adjusted until the currents in the two circuits are equal in magnitude and opposite in phase. From these values of capacitance and resistance the power factor and dielectric loss are computed.

A diagram of the circuit is shown in Fig. 7. The detector used consists of a synchronous commutator and a d-c. galvanometer. The rectifier is provided with two sets of brushes spaced 90 electrical degrees apart so that when properly set the bridge may be balanced for either component (active or reactive)—each practically independently of the other.

The balance circuit is unique in the use of a four-dial 100,000-ohm resistance box in connection with a

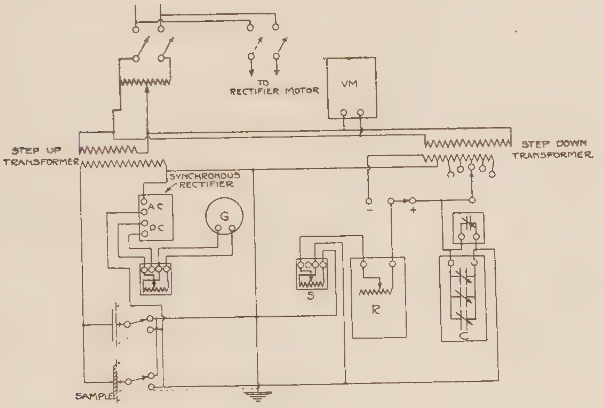

FIG. 7

universal shunt in order to simulate a continuously variable resistance of 0- to 500-megohm range. This is obtained by connecting the shunt across the detector and using the movable point as a connection for the resistance circuit.

Under certain conditions the resistance component required of the balance circuit is negative. Such a condition is provided for by an additional winding on the balance transformer as shown in Fig. 7.

The equipment used in this bridge consists of

1 D-c. reflecting galvanometer
1 Lamp and scale
1 Synchronous commutator
1 10,000-ohm galvanometer shunt
1 2000-ohm galvanometer shunt
1 4-dial, 100,000-ohm resistor
1 3-dial, 1 micro-microfarad mica condenser
1 1000-micro-microfarad variable air condenser
1 High-resistance voltmeter
1 Voltage regulator
1 Small step-down transformer
1 Testing transformer
1 High-voltage variable air condenser

In this method also, both the sample and the air condenser are kept connected to the testing transformer, each being connected directly to ground when not connected into the test circuit. This maintains circuit conditions constant at all times.

A set of typical test data is as follows:

	Air Condenser	Sample
Capacitance reading	0.2048	0.4378
Resistance reading	84000	42100
Shunt used	20	5
Tan ϕ	0.0077	0.0288
Power factor of sample, per cent		2.11

The tangent of the *apparent* defect angle, ϕ, is computed as for a parallel circuit

$$\tan \phi = \frac{l}{\omega C R S} \tag{11}$$

where

$\omega = 2 \pi f$
C = Capacitance read
R = Resistance read
S = Multiplying power of shunt

The defect angle of the sample is then the difference of these two angles, and since the angles are small,

Power factor $= \tan \phi_2 - \tan \phi_1$

where

ϕ_1 = the apparent defect angle of the air condenser

and

ϕ_2 = the apparent defect angle of the sample

The capacitance of the test sample is obtained from the capacitance read by

$$C_s = C \times r \tag{12}$$

where

C_s = Capacitance of sample
C = Capacitance read
r = Transformer ratio between test and balance circuits.

The time required for readings is about three minutes per test point. This includes the time for balances against both the air condenser and the sample.

Computations are not readily made during the test so that the time required for complete results on a test of six test points would be about one-half hour.

The sensitivity of this equipment is a function of the current in the test circuit and the galvanometer used. Since a d-c. galvanometer of medium high sensitivity (500 meg.) is used, the resultant sensitivity is high.

Accuracy is such that capacitances of the order of 50 micro-microfarads can be measured to within better than one per cent, while the power factor can be determined within ± 0.05 per cent (absolute value).

The bridge is extremely sensitive to leakages, so that all high-potential parts must be completely

shielded and all low-potential wiring metallically sheathed.

Frequency and voltage change affect the results only in so far as they change the properties of the test sample.

Potential waves of other than sine characteristics affect both the test and balance circuits alike and cause error only if neglected in the computations—the bridge

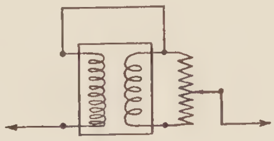

FIG. 8

determines the capacitance and resistance components for the wave applied.

Advantages:
1. Rapid operation
2. Simple operation
3. Very high sensitivity
4. Measurement range
   Capacitance 1-1000 micro-microfarads
   Power factor 0-100 per cent
5. Independent of frequency and voltage variations
6. Accuracy high

Disadvantages:
1. Very sensitive to leakages

Appendix I

THE USE OF THE REFLECTING ELECTRODYNAMOMETER AS A UNIVERSAL SHUNTED AMMETER

There are two methods of using the reflecting type electrodynamometer as a universal shunted ammeter. The first is that shown in Fig. 8. In this case only one coil is shunted and, providing the dynamometer has a uniform watt scale, the instrument follows the law,

$$\Delta S = K^2 I^2 \text{ or } I = \frac{\sqrt{\Delta S}}{K} \qquad (13)$$

where

Δ = the deflection in millimeters
S = the multiplying factor of the shunt
K = the ammeter constant
I = the current

It is preferable under some circumstances to shunt

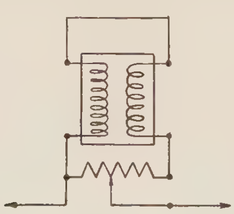

FIG. 9

both coils as shown in Fig. 9. The instrument then follows the law,

$$\Delta S^2 = K^2 I^2 \text{ or } I = \frac{S\sqrt{\Delta}}{K} \qquad (14)$$

In this latter case, if the instrument can be calibrated to be direct reading on one shunt the product of the reading on this scale and the shunting value gives the current on any shunt. In the first case it is necessary to compute the constant over the range used and then the current which is a longer process.

Appendix II

DETERMINATION OF COMPENSATION

a. Using a "no-loss" Air Condenser.

To determine the correct wattmeter compensation for a given voltage, set air-condenser plates as close together as safe operation permits and read the wattmeter deflection for a series of values of "compensation resistance." These results when plotted, with wattmeter reading as abscissas and the square of the "compensation resistance" as ordinates, will give a straight line. Similar sets of data are then taken for a wider setting of the air condenser. These straight lines should then all cross at a point, corresponding to the correct value of compensation, at which point the wattmeter reading should be a constant regardless of the condenser spacing.

While this method is described as for a "no-loss" air condenser, it applies equally well for a "constant-loss" variable condenser. Leakages play no part, providing they are constant for each voltage.

This procedure, while applying to single-phase equipments in particular, is readily adapted to three-phase equipments. In this case, each phase is handled separately as for single-phase determinations and then the average of the three values used as the correct three-phase compensation.

b. Using a Built-up Three-Phase Load.

A second scheme, sometimes more convenient for determining three-phase compensation, is to take three single-phase loads of approximately the same capacitance and loss, say three pieces of single-conductor cable; on which determinations can first be made by single-phase test methods. These loads can then be combined into a three-phase load and the "compensation resistance" adjusted until the loss measured under three-phase potential equals the sum of the losses measured at a corresponding single-phase potential.

Appendix III

EFFECT OF INCORRECT COMPENSATION IN WATTMETER SHUNT

Incorrect compensation in the wattmeter shunt will introduce no error if the phase defect compensation method is used. Any such phase error will affect both balances of the wattmeter alike and hence be eliminated when the difference is taken.

In the straight wattmeter methods, however, incorrect compensation in the wattmeter shunt will cause an error unless the potential circuit compensation values are obtained as in Appendix II. Mathematical analysis and actual tests have shown that any error

caused by incorrect compensation in the wattmeter shunt appears as a constant angular error independent of shunt position.

Appendix IV

Effect of Slightly Unbalanced Voltages on Three-Phase Measurements

When making three-phase measurements the natural tendency is to adjust the voltage on each phase just before taking a reading. This, however, means that when the three-phase supply is slightly unbalanced the three readings are taken for three different voltages on the cable as a whole. It has been found a better practise to hold the voltage on one-phase constant during all the measurements on all phases and let the others remain slightly high or low in voltage. In this way, readings on the three phases correspond to a given condition though they will not correspond to a balanced condition.

Again, any unbalance in voltages means that there may be slight phase shifts sufficient to make it impossible to analyze the individual wattmeter readings and get any idea of conditions in the insulation of each of the three conductors forming the load. In fact, it is not unusual to get negative readings on one phase, though the total is positive in value.

Appendix V

The Three-Phase Wattmeter Switch

To determine the power loss and reactive volt-amperes in a three-phase test circuit, using one wattmeter, requires a large amount of switching. Fig. 10 shows the operations to be made. Points X, Y and Z must all connect to G, either directly or through the

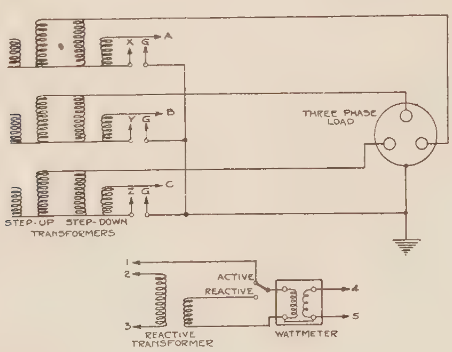

Fig. 10

current element of the wattmeter. With the current element of the wattmeter inserted between X and G, the potential element must connect to A and X, while the potential element for reactive volt-ampere measurements must connect to B and C. When the current element of the wattmeter is moved to connect between Y and G, the point X must again be connected to G and all the potential connections changed accordingly.

All of this switching with ordinary knife switches makes a very complicated and unwieldy arrangement. Accordingly, there has been developed at these Laboratories a simple-switching element which accomplishes in a single operation all of the necessary switching when changing from one phase to another. A diagrammatic view of this switch is shown in Fig. 11. The circles represent circular studs mounted in and insulated from the switch base. Connections are made to these studs as shown, the letters and numbers corresponding to those in Fig. 10. The upper or movable part of the

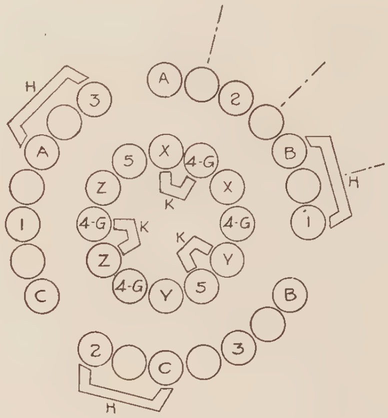

Fig. 11

switch rotates about the center and carries the spring contacts H and K which bear on the fixed studs. This switch in 60 deg. rotation provides correct connection of the wattmeter in each of the three phases.

Appendix VI

Shielding, Grounding, Etc.

In connection with all measurements made at high potential, shielding and guarding are important factors. In the three methods described in this paper, shielding is essential. All high-voltage parts, leads, etc., must be well shielded. All low potential wiring is best when done with metal-sheathed wire.

Shielding is most readily done when one side of the testing transformer and the transformer tank can be grounded. All the single-phase test equipments described in this paper are operated with one side of the testing transformer grounded. The grounding of the transformer and shielding protects the operator against contact with high-voltage parts.

As an additional protection to the operator, these testing equipments have been designed as "one-man sets," that is, they are built for complete operation by a single operator. All are equipped with safety switches which make it necessary for the operator to be in his place at the instrument table in order to put voltage on any of the equipment.

Abridgment of

Sag Calculations for Transmission Lines

BY H. B. DWIGHT[1]
Member, A. I. E. E.

***Synopsis.**—A set of sag formulas is presented, in the form of convergent series which give accurately the results of the hyperbolic catenary formulas. The series are useful for calculating almost any practical transmission line span, long or short.*

Trial and error methods are not used. First, the sag or deflection is calculated for a given maximum tension in the cable. Then, changes in temperature corresponding to changes in deflection and loading are computed. This procedure is followed whether the supports are at equal heights or at unequal heights.

A formula is presented for the deflection from the line joining the supports, when the elevations are unequal. This is useful in sighting from tower to tower, as shown in Fig. 2.

A few examples are worked out and some derivations of formulas are given. In the last appendix instructions are given with regard to allowing for the change in weight per ft. with change in length of cable.

SAG calculations for transmission lines are frequently made by means of formulas based on the assumption that the curve of a cable in a span is a parabola. Formulas for the calculations are also published, which use the equation for the catenary, a curve so named because it is the shape of a suspended chain. This equation involves hyperbolic cosines.

In this article is presented a group of convergent series which will be found convenient and accurate for making sag calculations. Provided enough terms are computed, these give the results of the hyperbolic catenary formula as accurately as desired. Usually, two or three terms are all that are required. Since the series are convergent series derived from the expansions of hyperbolic functions, they can be said to be themselves hyperbolic formulas. The first term of the series is in many cases the same as the well-known parabolic formulas[2], the majority of which consist of only one term. The series herewith presented should therefore be easily understood and applied by those accustomed to the parabolic formulas.

The series moreover give directly and automatically the percentage error involved by using the parabolic formulas. Even where the latter have good accuracy, it is always worth while estimating the amount of their error in a given case. Often the worst feature of an approximate formula consists in the fact that the amount of its error is not indicated and remains unknown, so that in some more or less unusual case the error may be unexpectedly large. An approximate formula in the form of a convergent series is much safer to employ, since when the terms do not become smaller and smaller, the last one being negligibly small, it is obvious that the formula is not applicable to the case considered.

If, therefore, a formula is really the first term of a convergent series, it is practically always advisable to publish two or three terms of the series, so that the appropriateness of the formula for a given case may be quickly estimated.

The series are given in the form in which they can be most conveniently used for practical sag calculations. A few examples of their use are described, and in an appendix there is given the derivation of some of the series. The derivation of the others can be obtained by following the method of the examples given.

The description of the engineering problem is usually as follows: A certain maximum tension T is specified for a cable and it is desired to know what will be the sag corresponding to this tension under given conditions of temperature and wind and of ice loading. Further, it is desired to know what changes in temperature and tension correspond to given changes in sag or in loading. These results are required when the two ends of the span are supported at the same height or at unequal heights.

In preparing the formulas, the use of trial and error methods has been avoided. These involve more work than direct calculations, and have a greater liability of error. If values of temperature are assumed, such as 40 deg. or 60 deg., a trial and error process is required at some stage of the calculations. Accordingly, values of sag or tension are assumed, and temperatures are obtained by direct calculation.

This provides data for drawing a series of curves of sag plotted on temperature, separate curves being drawn for different lengths of span. These lengths of span may be the actual lengths for the transmission line being designed, or they may be even hundreds of ft., such as 200- 400- 600 ft., etc. In the latter case, new curves may be plotted from the first set, so as to show sag plotted against span, separate curves being plotted for specified temperatures such as 20 deg., 40 deg., 60 deg., etc., and for specified loadings.

These procedures do not involve trial and error processes. The drawing of the curves described above deals only with the final results, after temperatures have been calculated. This is not likely to produce errors in the same way as the use of curves for intermediate stages of the calculations.

Attention should be called to a paper by J. S. Martin,[3] containing a very complete table for calculating sags

1. Professor of Electrical Machinery, Massachusetts Institute of Technology, Boston, Mass.

2. See articles on sag calculations by L. E. Imlay in the *Electric Journal* of February, 1925, and succeeding issues.

Presented at the Regional Meeting of District No. 1 of the A. I. E. E., Niagara Falls, N. Y., May 26-28, 1926. Complete copies available to members on request.

3. "Structural Engineering Problems in Transmission Line Construction," by J. S. Martin, *Proceedings* Engineers' Society of Western Pennsylvania, November 1922, page 309.

when the supports are at equal heights. Formulas are given for using the data in the table when the supports are at unequal heights but it is stated that the precision is not as great as for the case of equal heights, on which the calculations for the tabulated data were based. A method of successive approximations is described for obtaining sags at specified temperatures. While this involves some work, it is an orderly procedure leading to the desired result.

Sag Formulas

It is to be particularly remembered that in the formulas in this paper, l represents a half span only.

Supports at Equal Heights

$$\text{Sag or deflection} = d = l\left[\frac{1}{2}\,\frac{w\,l}{T} + \frac{7}{24}\left(\frac{w\,l}{T}\right)^3 + \frac{241}{720}\left(\frac{w\,l}{T}\right)^5 \ldots\right]\text{ft.} \quad (1)$$

where $l = \frac{1}{2}$ span $= \frac{1}{2}$ horizontal distance between supports in ft.

T = tension in pounds, in cable at supports, where the tension is greatest.

w = resultant loading in lb. per ft. of cable. Note that $w^2 = v^2 + h^2$ where v is the vertical force per ft. acting on the cable due to gravity on the cable itself and on the ice covering, if any, and where h is the horizontal pressure in lb. per ft. due to wind. The deflection d is not vertically downward. The distance vertically downward by which the lowest point of the cable is lower than the supports is $\frac{v\,d}{w}$ ft.

When the deflection, d, is given,

$$T = w\,l\left[\frac{1}{2}\,\frac{l}{d} + \frac{7}{6}\,\frac{d}{l} - \frac{4}{45}\,\frac{d^3}{l^3} \ldots\right]\text{lb.} \quad (2)$$

The unstressed length of cable in the span is

$$L_u = 2\,l\left(1 + \frac{2}{3}\,\frac{d^2}{l^2} - \frac{14}{45}\,\frac{d^4}{l^4} + \frac{278}{945}\,\frac{d^6}{l^6} \ldots\right) - \frac{wl^2}{A\,E}\left(\frac{l}{d} + \frac{5}{3}\,\frac{d}{l} + \frac{4}{9}\,\frac{d^3}{l^3} \ldots\right)\text{ft.} \quad (3)$$

where A = area of cross section of cable, in square inches and E = modulus of elasticity in pounds per square inch.

The first line of formula (3) gives the actual perimeter of the catenary, and the second line gives the stretch in the conductor.

To find the changes in temperature, t, corresponding to changes in deflection, d, and loading, w, find values of L_u corresponding to certain values of d and w. The changes in L_u are due to temperature, if the cable is assumed fastened to rigid supports, and

$$t = \frac{L_u - L_{u0}}{a\,L_{u0}}\text{ deg.} \quad (4)$$

where t is the change in temperature,
L_{u0} = value of L_u at the lower temperature,
L_u = value of L_u at the higher temperature, and
a = temperature coefficient of expansion per degree. If a is specified per degree Fahrenheit, then t is in degrees Fahrenheit. Note that

$$L_u = L_{u0}\,(1 + a\,t)\text{ ft.} \quad (5)$$

When a is defined as the increase per degree above a certain temperature, then L_{u0} should be that temperature, in using equation (4) or (5).

Curves can be plotted of d against t. Different curves for different values of w can be plotted.

To find changes in load, w, corresponding to changes in d at a given temperature, insert values of d in equation (3). The value of w which will give the value of L_u for the given temperature, is obtained directly. L_u is given by equation (5).

Changes in temperature corresponding to changes in tension T are given by the following equation, and by equation (4).

$$L_u = 2\,l\left[1 + \frac{1}{6}\left(\frac{w\,l}{T}\right)^2 + \frac{7}{40}\left(\frac{w\,l}{T}\right)^4 + \frac{241}{1008}\left(\frac{w\,l}{T}\right)^6 \ldots\right] - \frac{2\,w\,l^2}{A\,E}\left[\frac{T}{w\,l} - \frac{1}{6}\,\frac{w\,l}{T} - \frac{7}{120}\left(\frac{w\,l}{T}\right)^3 \ldots\right]\text{ft.} \quad (6)$$

Curves of tension, T, against temperature, t, can be plotted.

Supports at Unequal Heights

It is usually desirable to find first a solution of the catenary for a given maximum tension T at the higher support where the tension is the greatest, as was done in the case when the supports were at equal heights. Then, changes in temperature, loading and tension can be calculated, corresponding to changes in deflection.

Let v and h be the vertical and horizontal forces per foot acting on the cable, as previously defined. Then, $w^2 = v^2 + h^2$. Let p be the vertical height by which one support is higher than the other and let $2\,l$ be the horizontal distance between the supports.

$$q = \frac{p\,w}{v}\text{ ft.} \quad (7)$$

$$2\,k = \sqrt{4\,l^2 - q^2 + p^2} = 2\,l - \frac{(q^2 - p^2)}{4\,l} - \frac{(q^2 - p^2)^2}{64\,l^3} \ldots\text{ft.} \quad (8)$$

These dimensions are shown in Fig. 1, which is drawn in the plane of the cable and not in a vertical plane.

·If h, the wind pressure, is zero, then $q = p$ and $k = l$

Equation (**8**) is based on the fact that the square of the distance between the supports is equal to $4\, l^2 + p^2$ and to $4\, k^2 + q^2$.

Let

$$b = \frac{q}{2\,k} \tag{9}$$

$$\begin{aligned} m = k & \left(1 - b^2 + \frac{2}{3}\, b^4 - \frac{8}{15}\, b^6 \ldots\right) \\ & + \frac{T}{w}\left(b - \frac{2}{3}\, b^3 + \frac{8}{15}\, b^5 - \frac{16}{35}\, b^7 \ldots\right) \\ & - k\left(\frac{w\,k}{T}\right)\left(\frac{2}{3}\, b + 0 + \frac{2}{45}\, b^5 \ldots\right) \\ & - k\left(\frac{w\,k}{T}\right)^2\left(\frac{2}{3}\, b^2 + 0 \ldots\right) \\ & - k\left(\frac{w\,k}{T}\right)^3\left(\frac{16}{45}\, b + \frac{8}{9}\, b^3 \ldots\right) \text{ft.} \end{aligned} \tag{10}$$

The deflection, $d + q$, is found from equation(**1**) putting $l = m$.

The distance vertically downward from the upper support to the lowest point of the cable is $\dfrac{v\,(d + q)}{w}$ ft.

For finding the effect of changes of temperature and loading, it would be possible to assume different values of T and find values of m and d as shown above. However, it will be a little shorter to assume values of H the horizontal tension and find m from the following:

$$\begin{aligned} m = k & + \frac{H}{w}\left(b - \frac{1}{6}\, b^3 + \frac{3}{40}\, b^5 - \frac{5}{112}\, b^7 \ldots\right) \\ & - \frac{k}{6}\left(\frac{w\,k}{H}\right)\left(b - \frac{1}{2}\, b^3 + \frac{3}{8}\, b^5 \ldots\right) \\ & + \frac{k}{30}\left(\frac{w\,k}{H}\right)^3\left(\frac{7}{12}\, b - \frac{17}{24}\, b^3 \ldots\right) \text{ft.} \end{aligned} \tag{11}$$

The deflection in this case is found from

$$d = n\left[\frac{1}{2}\,\frac{w\,n}{H} + \frac{1}{24}\left(\frac{w\,n}{H}\right)^3 + \frac{1}{720}\left(\frac{w\,n}{H}\right)^5 \ldots\right] \text{ft.} \tag{12}$$

$$\text{where } n = 2\,k - m \text{ ft.} \tag{13}$$

After m, n and d are found, using either (**10**) or (**11**) for m, the unstressed length of cable is found by applying equation (3) to each part of the span separately, as follows:

$$\begin{aligned} L_u = m & \left[1 + \frac{2}{3}\left(\frac{d + q}{m}\right)^2 - \frac{14}{45}\left(\frac{d + q}{m}\right)^4 \right. \\ & \left. + \frac{278}{945}\left(\frac{d + q}{m}\right)^6 \ldots\right] \\ & - \frac{w\,m^2}{A\,E}\left[\frac{1}{2}\left(\frac{m}{d + q}\right) + \frac{5}{6}\left(\frac{d + q}{m}\right) \right. \\ & \left. + \frac{2}{9}\left(\frac{d + q}{m}\right)^3 \ldots\right] \\ & + n\left[1 + \frac{2}{3}\left(\frac{d}{n}\right)^2 - \frac{14}{45}\left(\frac{d}{n}\right)^4 \right. \\ & \left. + \frac{278}{945}\left(\frac{d}{n}\right)^6 \ldots\right] \\ & - \frac{w\,n^2}{A\,E}\left[\frac{1}{2}\,\frac{n}{d} + \frac{5}{6}\,\frac{d}{n} + \frac{2}{9}\left(\frac{d}{n}\right)^3 \ldots\right] \text{ft.} \end{aligned} \tag{14}$$

Curves for sag, temperature, loading and tension can now be drawn, as described for the case of support as equal heights. If a value of H has been assumed, the tension at each support can be found by applying equation (**2**) or (**21**) to each part of the span. The tension at a support is somewhat greater than H, and is greater at the higher support.

If there is no horizontal part of the curve between the two supports, then m is greater than $2\,k$, and n is a negative quantity. See equation (**13**).

Where a value of H is assumed, a table, not too condensed, of hyperbolic sines can be used with equation (**18**) to find m. However, this would not give a direct calculation for m in terms of T, such as is given by equation (**10**). If the difference in elevation of the supports is unusually great compared with the length of the span, the series may not converge rapidly enough, and a table of hyperbolic sines and cosines may be required. In such a case, trial and error methods may be necessary in order to obtain the desired results.

An illustration of this type of calculation is given in Example V. Since it is a trial and error method, different values of H must be assumed until a satisfactory value of T is obtained.

When the supports are at equal heights, values of H may be assumed and a table of hyperbolic sines and cosines used in a somewhat similar manner to Example V. This usually requires more work than to use the series. This is a trial and error method if one is working to a specified value of T. It may be necessary to do this if the series do not converge rapidly enough, as with an unusually large ratio of sag to span, but this is not likely to occur with practical transmission-line spans having supports at equal heights. One should also refer to the table by J. S. Martin[4].

Deflection from Line of Supports

After the location of the lowest point O, Figs. 1 and 2, and, therefore, the complete equation of the catenary

4. *Loc. Cit.*

for one set of conditions, have been found, it is possible to find by a direct calculation the vertical distance, $P\,Q$, from the line of the supports A and C to a tangent $B\,D$ which is parallel to $A\,C$.

In Fig. 2, $P\,Q = A\,B = C\,D$, and the two latter distances may be measured on the towers and the line $B\,D$ be used for sighting to determine the correct amount of sag to give the cable when stringing it. For

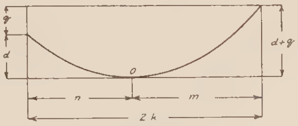

FIG. 1—SPAN WITH SUPPORTS AT UNEQUAL HEIGHTS

this purpose, assume that there is no wind or ice load, and so the cable hangs vertically. The calculation would be practically the same if wind load were included.

Let the equation of a line parallel to the line of the

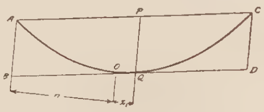

FIG. 2—DEFLECTION OF CABLE FROM LINE OF SUPPORTS

supports be $y = g\,x + f$ where g is known but where f is unknown. For this line, $\dfrac{d\,y}{d\,x} = g = \dfrac{p}{2\,l}$. The height of any point on the catenary above O is given by

$$y = \frac{H}{w}\left(\cosh\frac{w\,x}{H} - 1\right).$$ See Appendix I.

$$\frac{d\,y}{d\,x} = \sinh\frac{w\,x}{H}$$

If the line $B\,D$ is tangent to the catenary at Q, which is the point (x_1, y_1),

$$\sinh\frac{w\,x_1}{H} = g$$

Then

$$\cosh\frac{w\,x_1}{H} = \sqrt{1 + g^2}$$

$$y_1 = \frac{H}{w}\left(\sqrt{1 + g^2} - 1\right) \qquad (15)$$

$$x_1 = \frac{H}{w}\sinh^{-1} g$$

$$= \frac{H}{w}\left(g - \frac{1}{2\times3}g^3 + \frac{1\times3}{2\times4\times5}g^5 - \frac{1\times3\times5}{2\times4\times6\times7}g^7 + \ldots\right) \qquad (16)$$

Thus, numerical values of x_1 and y_1 can be obtained.

The height of P above O is $d + \dfrac{p\,(n + x_1)}{2\,l}$ and therefore,

$$P\,Q = A\,B = C\,D = d + \frac{p\,(n + x_1)}{2\,l} - y_1 \qquad \textbf{(17)}$$

all parts of which are known.

Example I. Find the difference in temperature for the following two sets of data for the same span:

$$2\,l = 800 \text{ ft.}$$

$$\frac{w\,l}{T} = 0.131\,28$$

$$\frac{w}{A\,E} = 0.000\,000\,757\,2$$

For the higher temperature, without wind or ice load,

$$\text{sag} = 23.176\,0 \text{ ft.}$$

$$\frac{w}{A\,E} = 0.000\,000\,297\,6$$

Temperature coefficient 0.000 0096

By formula (**6**),

$$L_{u0} = 800\,(1 + 0.002\,872\,4 + 0.000\,051\,9 + 0.000\,001\,2\ldots) - 800\,(0.002\,307\,0 - 0.000\,006\,6 + 0.000\,000\,04\ldots)$$
$$= 800 \times 1.000\,625\,2.$$

By formula (**3**),

$$L_u = 800\,(1 + 0.002\,238\,1 - 0.000\,003\,5 + 0.000\,000\,01\ldots - 0.001\,027\,3 - 0.000\,005\,7 - 0.000\,000\,01\ldots)$$
$$= 800 \times 1.001\,201\,6$$

By formula (**4**),

$$t = \frac{0.000\,576\,4}{0.000\,009\,6 \times 1.000\,625\,2} = 60.1 \text{ deg. fahr.}$$

This checks the result given in Mr. Martin's[5] paper.

Example II. Find the deflection for the following span[6]:

$2\,l = 2000$ ft.

Supports at equal heights.

$T = 70{,}000$ lb.

$w = 4.700$ lb. per ft.

$$\frac{w\,l}{T} = \frac{4.700 \times 1000}{70\,000} = 0.067143$$

$$\frac{l}{2}\left(\frac{w\,l}{T}\right) = 33.571$$

By equation (**1**), $d = 33.57 + 0.088 + 0.0005 = 33.66$ ft.

This agrees with the value of 33.6 ft. given in

5. Problem IV of the article by J. S. Martin, *Loc. Cit.*

6. Problem 2, p. 11, Transmission Line Design by F. K. Kirsten, 1923, Bulletin No. 17, University of Washington, Seattle, Wash

reference 6. It is seen that the series gives quickly and directly a precise solution of this problem, and the degree of precision of the calculation is indicated by the convergence of the series. The first term is the well-known parabolic formula.

Example III. Find the horizontal point for the following catenary[7]:

$2\,l = 2700$ ft.

Supports at unequal heights, $p = 179$ ft.

$T = 60\,587$ lb. at the higher support.

$h = 1.321$ lb. per ft.

$v = 2.870$ lb. per ft.

$w = 3.158$ lb. per ft.

$$q = \frac{p\,w}{v} = 197.0$$

$$2\,k = 2698.75$$

$$b = \frac{q}{2\,k} = 0.0730$$

By equation (**10**),

$m = 1342.2 + 1395.6 - 4.6 - 0.02 - 0.01 = 2733.2$ ft.

$n = 2698.7 - 2733.2 = -34.5$ ft.

The above paper gives $m = 2608.8$ ft. and $n = +91.2$ ft., but it neglects the fact that the cable lies in an oblique plane, and the dimension $p = 179$ ft. does not lie in that plane.

Example IV. Find the deflection for the following span[8]:

$2\,l = 4279$ ft.

Supports at unequal heights, $p = 185.5$ ft.

$T = 33000$ lb. at the higher support.

$h = 2.036$ lb. per ft.

$v = 2.623$ lb. per ft.

$w = 3.322$ lb. per ft.

$$q = \frac{p\,w}{v} = 235.0 \text{ ft.}$$

$$2\,k = 4276.57 \text{ ft.}$$

$$b = \frac{q}{2\,k} = 0.05495$$

By equation (**10**),

$$m = 2132 + 545 - 17.0 - 0.2 - 0.4$$
$$= 2659 \text{ ft.}$$

By equation (**1**),

$$d + q = 356 + 15 + 1$$
$$= 372 \text{ ft.}$$

The paper referred to above states that the deflection from the upper support is

$$9933.77 - 9615.44 = 318.33 \text{ ft.}$$

and that the deflection from the lower support is

$$9786.91 - 9615.44 = 171.47 \text{ ft.}$$

The difference between these deflections is 146.86 ft. which is less than the inequality in height of the supports, namely 185.5 ft. The difference of the deflections in the oblique plane should, however, be greater than 185.5 ft. In the appendix of the above paper, the equation $k_0 = k \cos\theta$ should be $k_0 = \dfrac{k}{\cos\theta}$, and formula (**3**) should be $k\left(\dfrac{1}{\cos\theta} - 1\right)$ instead of $k\,(\cos\theta - 1)$

$$\left[\,k = 185.5 \text{ ft. and } \cos\theta = \frac{2.623}{3.322}\,\right]$$

Example V. To illustrate the use of a table of hyperbolic sines and cosines,

Let $H = 31940$ in Example IV.

$$\frac{w\,k}{H} = \frac{3.322 \times 213\,8.28}{31940} = 0.222\,40$$

$$\sinh 0.222\,40 = 0.224\,24$$

$$\sinh \frac{w\,(k-n)}{H} = \frac{q\,w}{2\,H \times 0.224\,24}$$

$$= \frac{235.0 \times 3.322}{2 \times 31940 \times 0.224\,24}$$

$$= 0.054\,50$$

$$\frac{w\,(k-n)}{H} = 0.054\,47$$

$$n = 2138.28 - \frac{0.054\,47 \times 31940}{3.322}$$

$$= 1614.6 \text{ ft.}$$

$$m = 4276.57 - 1614.6 = 2662.0 \text{ ft.}$$

The value of T can now be calculated, and it will be slightly different from 33,000 since a value of H was assumed as part of the trial and error method.

The complete paper contains an appendix, here omitted, giving derivations of formulas.

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7. Problem with cable loaded, Table VII, Transmission Line Design, by G. S. Smith, Journ. A. I. E. E., Dec., 1925, p. 1352. See complete paper.

8. "Mississippi River Crossing," by H. W. Eales and E. Ettlinger, Journ. A. I. E. E., Oct., 1925, first problem in the appendix. See complete paper.

LIGHTED STREETS

The lighting of public streets was originally a private undertaking, and the first city ordinance was passed in London in 1414, requiring all citizens to hang lamps before their doors at dark. Municipal street lighting originated in 1558 in Paris. Oil-burning lamps were used till 1813, when gas was adopted. In London electric street lighting is a development of the last forty years.

Discussion at Midwinter Convention

CARRYING CAPACITY OF 60-CYCLE BUSSES FOR HEAVY CURRENTS[1]

(LeClair)

New York, N. Y., February 9, 1926

H. B. Dwight: Usually it is found undesirable to place copper straps across lines of magnetic flux, but they should be placed parallel to the magnetic field as much as possible. Accordingly, where the phases are separated, I should suggest placing the straps parallel to the sides of an equilateral triangle, as in Fig. 1 of this discussion. If arrangement has not been tried out, it should be tested in comparison with the arrangements shown in Fig. 6 of the paper.

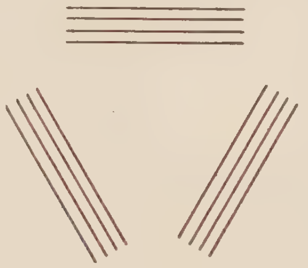

Fig. 1—Proposed Arrangement of Bus Bars

It is not always necessary to separate widely the conductors of different voltages. If the voltage is not over 250 volts, parallel straps connected + — + — etc., or A, B, C, A, B, C, etc., give extremely good results. In this way, currents up to 50,000 amperes at about 200 volts have been carried without trouble from skin effect, proximity effect, or reactance drop, as is well known in heavy electric-furnace work.

C. F. Wagner: The problem of current capacity of busses, by its very nature, is largely empirical. Mr. LeClair has contributed valuable experimental data to the general fund of knowledge on the subject.

I wish to question the statement made by Mr. LeClair on the fourth page of his paper which reads as follows: "In Mr. Wagner's article for single-phase busses he draws the curve from the outer edge to the center of the bar and assumes that the same condition holds from the center to the opposite edge of a bar. This is perfectly true in some cases but not at all true in others; and the electrical center, or the point of minimum current, in a bar may not be the physical center." While this statement is perfectly true, Mr. LeClair draws the inference that I would probably have made the same assumption, and, of course, been wrong, had I had a different set-up. The fact is that my assumption was correct for the particular case chosen, and for other cases in which the distribution was unsymmetrical I determined the distribution in the entire bar. Perhaps I am unjustified in interpreting the statement in this light and considering the matter merely one of an unfortunate choice of expression.

Regarding the use of magnetic steel for increasing the carrying capacity, the cut-and-try method of application does not appear to me to be an insurmountable difficulty. In connection with the magnetic balancers I should also suggest the use of radiating fins to carry away the iron loss in the balancers.

A. E. Kennelly: In the paper by Mr. LeClair, skin effect and proximity effect are fully referred to, but edge effect does not appear to be mentioned. If we take a flat strip of copper and allow it to carry direct current (the return conductor remote), we know, except for temperature variations, that the current density will be the same in all parts of the cross-section. However, when the strip carries an alternatng current, there may be negligible skin effect because the strip is thin. But the current density will not be uniform; it will tend to be much greater at the edges. That effect can be eliminated completely by bending up the strip edges so as to form a tube. The current density then becomes uniform everywhere, and the edge effect disappears.

That is a well known phenomenon and what we have in Mr. LeClair's paper is a mixture of edge effect and proximity effect. For example in the case of Fig. 2, you see that there is edge effect, but there are also proximity effects at the edges which are near to the other conductors. It is exaggerated, so to speak, by the vicinity of the neighboring conductors. But if the bus bars were removed or separated by a considerable distance, there would still be edge effect and the linear resistance of that conductor would be greater than that which would be obtained even though the skin effect were extremely small.

When the conductor is bent round, we tend to eradicate the edge effect, but we do not get rid of the proximity effect, and Curve 3, which represents Figure B, I think has an advantage in carrying capacity over Curves 1 and 2, corresponding to constructions where the edge effect is more pronounced. As Mr. LeClair has pointed out so well, it is very difficult to make measurements upon the resistance of bus bars owing to their size and cross-section. The linear resistance of the bars microhms per meter is so small that it is very often necessary, as he says, to infer the resistance from the temperature observations because where the point of resistance goes up including skin or edge effect, the temperature also will go up. On the other hand, we have to remember that all these effects of extra current density depend upon the resistivity and where the temperature goes up, the resistivity goes up too and modifies the effect. We thus get only an approximate measurement. The changes of temperatures involved will alter the distribution of current density.

S. W. Mauger: This subject began to interest the writer many years ago when rather exhaustive tests were made to determine a practicable and efficient method of carrying heavy currents. As Mr. LeClair states, the old standard of 1000 amperes per sq. in. and the practise of simply adding another parallel bar of copper to obtain increased capacity had become inadequate, especially for 60-cycle current. After trying many schemes, the writer suggested the plan now standard with the General Electric Company and referred to by Mr. LeClair in foot-note No. 5. One of the features of this scheme is the increased ventilation obtained and another is the so-called "box" arrangement which takes care of the skin effect. The first feature was very useful in carrying heavy d-c. currents and it was found that two sets of 4-in.-wide bars in vertical relation with 2-in. vertical space between them would carry at least as much current as one set of 10-in. bars, thereby saving 20 or more per cent of copper.

It may be inferred from Mr. LeClair's statement in the first paragraph on the fifth page of his paper that the General Electric Company scheme is suitable only for isolated phases and for currents not exceeding 7400 amperes at 60 cycles. Such an inference would be incorrect as the scheme allows the phases to be on close centers and by using wider bars with slightly more space between bars for increased ventilation, it has been possible to carry much greater currents than 7400 amperes, although this is as high as the published table goes. When there are long runs of bars for heavy a-c. current, transposition can be resorted to which overcomes any difficulty resulting from unequal distribution.

It would seem that with Mr. LeClair's proposed arrangement there would be difficulty in taking off connections from the bus bars except those of small capacity.

Mr. LeClair mentions the matter of permissible temperatures of bus bars. The rule of 30 deg. cent. rise is, of course, based on

1. A. I. E. E. Journal, January, 1926, p. 9.

an ambient temperature of 40 deg. cent. to give a maximum total of 70 deg. cent, the total being what we must have in mind. Naturally, if the ambient is lower, the rise may be higher, but for a standard rule, it is not safe to consider varying ambient temperatures. We must also remember that switching devices are designed on the basis of the A. I. E. E. Rule of 30 deg. cent. rise and bars connected to these devices must not have a higher temperature. Oxidation is much more rapid above 70 deg. cent. than below it, and it does not seem wise to consider an ambient of less than 40 deg. cent.

E. G. Bern (communicated after adjournment): In Mr. LeClair's contribution is a statement from which may be inferred that 7400 amperes is the feasible limit for a 60-cycle, three-phase bus with double-tier vertical laminations.

When dealing with currents of such magnitudes, the question of supporting the bus structure and its connections to withstand abnormal magnetic stresses usually demands a more liberal spacing of the bus phases. This is, of course, usually limited by available space, and by the permissible reactance, as mentioned by Mr. LeClair. By properly proportioning the design, it has been found entirely practicable to use this construction for very much higher capacities without neglecting any of the above factors, and at the same time to make connections in a convenient manner. Fig. 2 herewith shows this construction successfully applied to a bus of 11,000-ampere capacity, which, however, should not be considered as the practical limit. Under some conditions a transposition scheme of equalizing the load in the different sections of the bus has worked out to good advantage without undue complications.

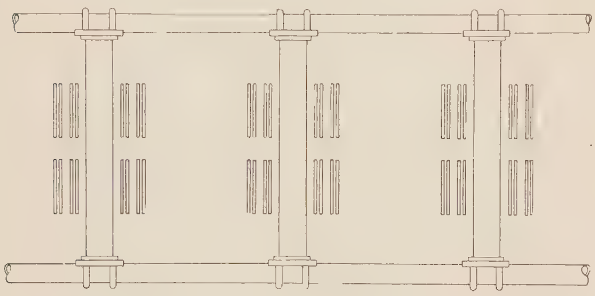

FIG. 2—BUS CONSTRUCTION, 10,000-AMPERE, 60-CYCLE, 3-PHASE

T. G. LeClair: At first thought it would seem undesirable to put copper straps across the lines of magnetic flux, and it would appear advisable to set up the three-phase bus with the bars arranged as shown in Fig. 3 herewith. However, after a careful examination of test results, we come to the conclusion that, with this arrangement, the ratio of currents at points A and B is practically the same as the ratio of currents at points A and B in Fig. 4 herewith. The particular case on which we have the most information from our test results is a bus consisting of four bars of 8-in. by ¼-in. copper, in arrangements which approximate Figs. 1 and 2. In this case, it appears that the current at point A is nearly three times the current at point B for either arrangement. This means that with the arrangements shown in Fig. 3 most of the current will be carried by the bar facing the center of the triangle and the other bars will carry very little. In Fig. 4, the outer edge of each of the bars will be carrying much less current than the inner edge, but they will reduce the temperature because they act in the nature of radiators, which is not the case with the unused copper of Fig. 3.

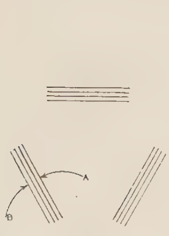

FIG. 3

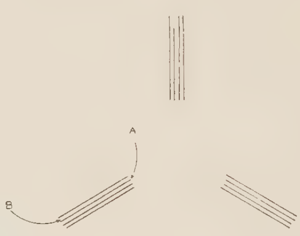

FIG. 4

I do not wish to convey the impression that Mr. Wagner was making a mistaken assumption in his previous article. Some warning is, however, necessary because the majority of busses will be set up on an arrangement wherein the distribution of current will be unsymmetrical.

On the matter of balancing currents by means of magnetic balancers around the bars, there are two different points of view to take. One is that of the manufacturer of switchboards who has factory conditions to deal with and close contact with the men doing the work. In this case magnetic balancers may possibly be used to advantage. Out in the field we have different conditions, and usually the class of men doing the work is one unfamiliar with what is required. The contact between the engineer and the construction men is not so close, and the expense of the cut-and-try balancing is altogether out of reason. Some other method of balancing is much less expensive and more satisfactory for all cases.

Dr. Kennelly has brought up an important point in the use of the terms "edge-effect" and "skin-effect." The difference in the significance of these terms should be made more clear. Fig. 5 herewith will probably explain my reasons for using the term skin-effect rather than the term edge-effect. This figure represents a single-phase circuit in which one of the busses is made up of laminated copper bars and the other of copper strands in the form of the cable. In the left-hand bus we all agree that due to skin-effect the current in the outer surface at C is much greater than the current at the center, D. Due to proximity effect the current at the point E is greater than the current at the point F, and by following the same reasoning in the right-hand bus, which, for the sake of clarity, I have made circular, we should still say that skin-effect is the cause of a greater current density at G than at H, and that proximity effect is the cause of the greater current density in bar J than in bar K. Now, if we arbitrarily take out the center bar of this bus and consider it separately we say that it is no longer skin-effect but edge-effect which causes the greater density at the point G than at point H. As I see it, edge-effect is a special application of the word skin-effect. Skin-effect should include any uneven distribution of the current in a bus or cable due to the flux created by the current in this bus, while proximity effect should include any uneven distribution caused by flux in an adjacent conductor. Regardless of the shape of the conductor, whether it be round, flat, or of any other shape, the uneven distribution due to the current in itself then causes skin-effect, and changing the shape changes the amount of this effect but does not change it from one type of effect to another. I do not wish to state that this is the best nomenclature to use for all cases, but I think it is time that we settle upon one definition by which we could all understand each other.

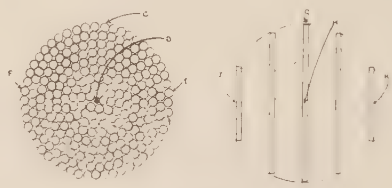

FIG. 5

We did not make any test on an arrangement of bars exactly like that described by Mr. Mauger and by Mr. Bern, but it appears that they would have some trouble due to proximity

effect unless the busses were spaced a reasonable distance apart. Of course, so long as we can increase the spacing between phases and between individual bars of the phases, we may increase the carrying capacity indefinitely. When we come to the greater current, however, the weights of copper to be used become of considerable importance, and it becomes advisable to study carefully which arrangement will give the best copper economy. Perhaps it will pay to use a slightly more expensive support in order to use less copper. The type of construction illustrated in Mr. Bern's discussion is very interesting, but unfortunately no dimensions are shown with which to make comparisons of the copper economy to be obtained with this or another arrangement.

Mr. Mauger's points on the matter of permissible temperature rise are very well chosen. When a bus is to be connected to some switching device designed for a 30-deg. cent. rise, it is obvious that the bus copper must operate at the same, if not at a lower, temperature. It is impossible to make contacts for use in switching devices as good as a stationary bolted contact, and they must be protected. There are, however, a great many places where a bus is not connected to switching devices, for instance, between a transformer and rotary converter, and in such cases experience has shown that considerably higher temperatures may be maintained without any trouble from oxidation.

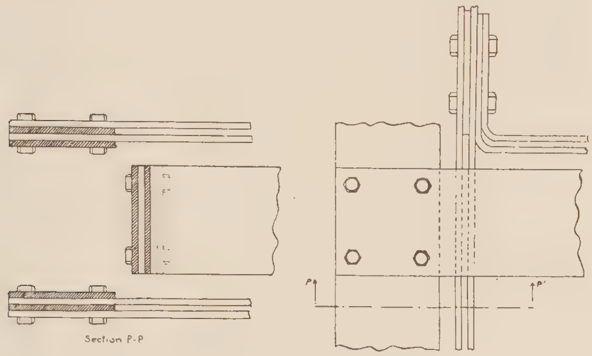

Fig. 6

Fig. 6 herewith shows a sample top on a bus for high capacity. Tops in other directions can be made with equal ease.

REFRACTION OF SHORT RADIO WAVES IN THE UPPER ATMOSPHERE

(Baker and Rice)

New York, N. Y., February 9, 1926

A. E. Kennelly: The paper is very timely and interesting because so much attention has been drawn in recent months, not to say years, to the marvelous properties of very short waves. The paper makes a definite and very reasonable attempt to explain some of those properties. The direct wave dies out at a relatively short distance from the sending station and then nothing more is heard of it or received from it until it has traveled a relatively great distance. That phenomenon repeats itself at least once.

Here we are between certain rival theories of refraction and reflection from effects produced in the upper atmosphere at a distance at which we can only guess. It is very remarkable that we know so little. We are necessarily ill-informed concerning the conditions that exist in the atmosphere at a distance of, let us say, fifty-kilometers above our heads, while fifty kilometers along the ground we can cover in an automobile in an hour or less.

The wonderful thing is that we are able already to form opinions, such as are expressed in the paper, as to what does take place in that region above our heads which is so near and yet so far. The promise is very brilliant that we shall be able to learn from radio observations, in the not far-distant future, the electrical properties of the atmosphere at distances from ten to 100 or more kilometers above the earth, and it will be very surprising if the information thereby gained does not have a marked influence upon weather forecasts at least in the region up to twenty or thirty kilometers above the surface.

Personally, I think it is early yet to form hard and fast opinions or to make very definite conclusions as to just what these phenomena are. We know that there must be refraction. We know that there must be rotary polarization and we also know that there must be reflection. Probably all three of these things occur simultaneously. I think we must therefore retain an open mind for the present—until more information can be secured by observation.

W. B. Kouwenhoven: The author's conclusions are similar to those of Dr. J. Zenneck who published a paper on this subject in "Elektrotechnik und Maschinenbau", Vol. 43, p. 593 and 612, 1925. Dr. Zenneck concludes from observations that radio waves enter the upper atmosphere and that these waves may come back to earth at some distant point because of refraction.

Radio transmission takes place by means of ground waves and by means of waves that pass through the upper atmosphere. In the case of short waves the ground radiation is rapidly absorbed as pointed out by the authors, while the absorption is much less for long-wave transmission.

The electric field produced by a radio wave in the upper atmosphere sets the ionized particles in motion. In the case of long waves the mean free path of the ionized particle is short compared to the wave length, and collisions occur. The energy is therefore absorbed and very little if any of the wave is refracted back to earth. In the case of short waves the absorption is much less in the upper atmosphere, and the wave is refracted and reaches the earth again at some point distant from the transmitter.

M. I. Pupin: Mr. Einstein would probably say that you are wrong when you say that the wave can be propagated by a velocity greater than the velocity of light wave. What would you answer if he did object?

W. G. Baker: I think it is one of the cases of distinction between the velocity of a group of waves and the phase velocity.

With reference to the question of reflection versus refraction raised by Dr. Kennelly, I believe that most of the people who talk about reflection from the Kennelly-Heaviside layer use it as an approximation; they do not wish to bother with the complexity introduced by refraction. Actually the transition from the neutral to the ionized medium must be gradual, and will therefore not be sufficiently abrupt to produce appreciable reflection except on the very long wave lengths. Unless the ionization changes by a large amount in a distance comparable with the wave length of the radio wave no appreciable reflection can occur, but electron refraction may easily bend the wave back to earth.

Rotary polarization and other effects due to the action of the earth's magnetic field on the electron motion will require consideration in a complete theory of the propagation of radio waves as Dr. Kennelly has pointed out. We have evaded that phase of the question as well as we could by dealing only with the case of short waves where the earth's magnetic field cannot have much effect. There is a certain resonance frequency of the electrons produced by the earth's magnetic field which corresponds to a wave length of about 214 meters. If we are working well above that frequency the effect of the earth's magnetic field on the motion of the electrons can be neglected without serious error.

We wish to thank Dr. Kouwenhoven for calling our attention to Dr. Zenneck's paper, and we are interested to hear that his conclusions concerning the propagation of short radio waves are similar to ours.

Recently there has been a good deal of surmising, on the part of radio men, as to the height of the ionized medium. Obviously we cannot speak of the height of the actual medium since we do not know where to say it begins, where the maximum is, or where

it ends. The effective height of the layer as judged by a sharp reflection theory will, of course, vary with the wave length, distance between transmitter and receiver, etc. On short waves we require a relatively large amount of ionization to bend the ray back to earth. Therefore the ray will penetrate deep into the ionized medium before it returns to earth. Here the apparent height of the layer as judged on the reflection theory may be very great. On longer waves a smaller ionization density is sufficient to bend the same ray back to earth so that the depth of penetration will be less and the apparent height of the medium will be lower than that estimated from the short-wave experiments. A further difference is brought in by the effect of the earth's magnetic field.

CIPHER PRINTING TELEGRAPH SYSTEMS[1]

(Vernam)

New York, N. Y., February 9, 1926

L. F. Morehouse: This work on the development of arrangements for secretly transmitting telegrams was done during the War under the direction of Mr. Gherardi. The problem was to see if a simple and effective means that would be entirely secret could be devised for handling telegraph business. The method used should be such that an enemy could not decipher the messages even if he could capture the mechanism used, thoroughly understand its operation, and obtain contact with the line circuits.

A large number of systems were studied. Of the many suggestions made, the most promising were set up and tested out in the laboratory. Various schemes for breaking up the dots and dashes were proposed, but in the last analysis all were found to be unsatisfactory. We found in studying this problem that many methods had been devised. Where mechanical devices were used, they involved, sooner or later, a repetition of the key. If there is such a repetition, the messages can be deciphered and the real secrecy has disappeared.

Printing telegraph methods were found to be more promising. The key in the form of a paper tape or resulting from the combination of two such tapes can be made as long as desired without repetitions with the result that the cipher becomes impossible to break. For ordinary business purposes, however, a simpler cipher using a key that might repeat at infrequent intervals would be entirely practical and sufficiently secret.

P. W. Evans: None of the present military codes or ciphers offers complete satisfaction in its security, speed or simplicity. The Signal Corps of the Army will appreciate any assistance or suggestions which may be offered on this important phase of our national defense problem.

CONCLUDING STUDY OF VENTILATION OF TURBO-ALTERNATORS MULTIPLE PATH RADIAL SYSTEM[2]

(Fechheimer and Penney)

New York, N. Y., February 9, 1926

S. L. Henderson: This paper covers the results of a considerable amount of experimental work done subsequent to the papers written in 1924 by Mr. Fechheimer and Mr. Bratt. As the later tests were made on stationary models, the constants could be determined more accurately than on a moving model, and the accuracy of the equations is demonstrated in the comparison between tests and calculations as given in Figs. 13 and 14. The results of this work are being used in the design of turbine generators with considerable practical benefit. On one design, in particular, it was possible to shorten the machine considerably through the use of these equations.

The choice of the number of vents and the division of these vents into intake and outlet zones is thus made relatively simple. The number of vents is determined by the velocity of air required in the radial vents to obtain satisfactory cooling on the sides of the vent spaces. The number of vents is also determined by the width of the iron package between vents which can be allowed without having an excessive temperature drop in the package. Several trials, as in most questions of design, must be made in order to obtain the best proportions. After the number of vents has been decided upon, the division of these vents into intake and outlet zones can be carried out through the use of the equations in this paper.

1. A. I. E. E. Journal, February, 1926, p. 109.

2. A. I. E. E. Journal, April, 1926, p. 347.

A NEW WAVE-SHAPE FACTOR AND METER[1]

(Doggett, Heim, and White)

New York, N. Y., February 11, 1926

J. J. Smith: When considering the effect of harmonics, it is perhaps well to divide them into different classes: (1) those which may give rise to resonant conditions or large circulating currents on the power circuit, (2) those which may give rise to telephone interference, (3) those which may give rise to radio interference, (4) those which may give rise to any other type of trouble that may be discovered. Let us consider, for instance, the case of telephone interference, as somewhat similar remarks will apply to other types of interference. In the telephone-interference-factor meter an attempt was made to weight the various harmonics in accordance with the experimental data available as to the interfering effect of each harmonic. A special type of network was designed to do this, and the impedance characteristics of such a network, which is used in the telephone-interference-factor meter, can be varied, within certain limits at least, to correspond with any new data which may show that it is desirable to weight the harmonics differently. In the method suggested by Messrs. Doggett, Heim, and White, no such adjustment is possible.

The method proposed may also be compared with a method such as the use of the telephone-interference-factor meter by noting the ratio between the maximum and minimum values obtained on machines in actual operation. The T. I. Fs. given on the machines of Table I of the 1919 Report of the A. I. E. E. Subcommittee on Wave Shape Standards vary from 11 to 550, while the ratios given by Messrs. Doggett, Heim and White vary from 2.746 to 3.724, giving a ratio of 50 to 1 with one method and 1.35 to 1 with the other.

It is well to remember that direct-current and other types of machines produce harmonics, and that it is undesirable to have a wave-shape meter which will apply to three-phase systems only. Also, in certain cases of telephone interference which have occurred on systems with the neutral grounded, it is the wave shape from line to neutral and not from line to line which is of interest.

I would like to inquire if the authors found any difficulty in making measurements on systems on which there were large variations in load. In making measurements of harmonics on such systems we have found that the magnitude of the harmonics varied with the load over short periods of time (in the order of one or two seconds). I wonder if fluctuations of this nature would not make it impossible to get a consistent curve from which to pick the maximum as in Fig. 5.

It may be well to consider the first paragraph of the paper by briefly considering what accuracy may be obtained in analyzing a wave obtained with the oscillograph. Let us assume an oscillogram has a maximum ordinate of 2 in. and that the line is of average thickness, which, in order to get a good film, may be 1/20 in. or less. Using a wave micrometer ruled in fortieths of an inch there is no reason why the values of the ordinates should not be measured to within half of one division or 1/80 of an inch. This is an error of 1 in 160 or let us say 0.7 per cent. As the probability is that all these errors will not be in the same direction, it would appear more proper to take, perhaps, half of this, or say 0.35 per cent, as the probable error in measuring

1. A. I. E. E. Journal, February, 1926, p. 131.

the oscillograms. Using this figure the maximum deviation in the first case quoted by the authors from the *Revue Générale de l'Electricité* should have been between the limits 2.6 per cent and 1.9 per cent or the maximum value is in excess of the average by about 15 per cent of the average value, and correspondingly less in the other case.

The large discrepancies quoted by the authors may be due to the inherent difficulty in superposing the equivalent sine wave of equal length in such a manner as to give the least difference, as required by A. I. E. E. Standards, 1922, No. 3274. It would be impossible, however, to explain them without making a detailed study of the calculations which were made in each case. Also, a comparison of the T. I. Fs. calculated from oscillograms and those taken direct with the T. I. F. given in the 1919 Report of the Subcommittee on Wave Shape of the A. I. E. E. Standards Committee, will show that the large discrepancies quoted by the authors cannot be the general rule. Furthermore, it should be remembered that by using a filter or some such device for stopping off the fundamental, a very much higher degree of accuracy in measuring harmonics may be obtained with the oscillograph.

F. K. Brainard: It is generally recognized that sine waves in a-c. apparatus are desirable and since commercial alternators frequently have voltage waves which differ considerably from sines, it would be highly desirable to have a wave-form factor which could be easily determined and which would be a measure of the detrimental effect resulting from a distorted wave. Various factors have been suggested including the following: (a) form factor, (b) peak factor, (c) telephone-interference factor, (d) differential distortion factor, (e) integral distortion factor, (f) curve factor, and (g) harmonic factor. None of these appears to be entirely satisfactory, partly because the detrimental effect of a distorted wave depends upon the trouble under discussion and partly because some of the above factors are not readily measured. If telephone interference is being considered, the telephone-interference factor is undoubtedly the proper criterion to apply, but if the core loss of transformers is under consideration or the dielectric strength of insulating material is being measured, it is quite obvious that some other factor should be used.

While this new factor gives the greatest weight to the seventh harmonic, there is not an exceedingly great variation in weight given between any of the harmonics, and in this respect it resembles the "harmonic factor" which is defined by Bedell as the ratio of the effective value of the harmonics to the effective value of the fundamental, but is superior to it in that it is very easily measured, although it is applicable to three-phase circuits only. Possibly an Institute rule using both the telephone-interference factor and this new factor specifying limiting values of both, would be desirable. In that case, the telephone-interference factor would limit possible telephone interference and this new factor would limit other troubles due to the presence of the lower harmonics.

The authors are to be complimented for the development of a wave-shape factor which gives promise of being a valuable one. The question now seems to be the determination of the value of this factor as a criterion for the comparison of voltage waves.

C. W. Bates: The paper contains a satisfactory analysis of the proposed method which should give reasonably correct values for the harmonics present, when the conditions are ideal. The paper does not, however, contain any investigation of the errors which may arise from such sources as the use of voltmeters containing some inductance, condensers whose loss is not negligible, and unbalanced line voltages. The entire theory of the proposed method rests on the assumption that when no harmonics are present the potential of the neutral point of the circuit used is displaced to such a point that the voltmeter readings have the ratio of 3.732. This is true only when both voltmeters are absolutely non-inductive, the condensers are absolutely without loss, and the voltages of the three phases are absolutely equal.

If it is assumed that each voltmeter has an inductance L in addition to its resistance R and that the condenser has a loss represented by its equivalent series resistance r in addition to its capacity c the ratio of the voltages indicated with exactly balanced three-phase line voltages will be approximately equal to $3.732\left[1+\sqrt{3}\left(\frac{\omega L}{R}-r\,\omega\,c\right)\right]$ when $R=\frac{1}{\omega c}$. The fractional error is then equal to $\sqrt{3}\left(\frac{\omega L}{R}-r\,\omega\,c\right)$ or practically equal to the difference of the angles of defect (from the ideal) multiplied by $\sqrt{3}$. The approximation in this result is due only to considering that the angles of defect are equal to their respective sines and tangents and that the cosines are equal to unity. These approximations are entirely justifiable for any voltmeters or condensers whose use could be considered.

The importance of these errors may be judged by considering two examples:

Voltmeters: $R = 1000$ ohms, $L = 53$ millihenries

$$\frac{\omega L}{R} = .02 \text{ at 60 cycles,}$$

$$\text{Condenser: } \frac{1}{\omega c}\ 1000 \text{ ohms, } r = 50 \text{ ohms}$$

$r\,\omega\,c = 0.05$ (3 deg. approximately)

The fractional error in the ratio will be equal to $\sqrt{3}$ $(0.02 - 0.05) = -0.052$ or -5.2 per cent. (By the exact expression this is 4.9 per cent, thus justifying the approximate expression given for the error). If the voltmeter inductance is 5.3 millihenries as may occur in the best modern dynamometer voltmeters and the condenser phase angle is 17 min. as might be found in a good mica condenser, each angle of defect is one-tenth the former value and the error is 0.52 per cent. Even this error is quite appreciable in the calculation of the method shown in the paper. Fortunately the errors due to inductance and to condenser loss are opposite in sign and therefore, by a suitable adjustment, they may be made to neutralize each other.

The error due to unbalanced three-phase voltage may be much greater and moreover varies continually with line-voltage fluctuations. This error may be readily analyzed by the use of the symetrical coordinates developed by C. L. Fortescue. By this method any unbalanced system of three-phase voltages is resolved into two balanced systems of opposite phase rotation. Since the direction of shift of the potential of the neutral point is determined by the phase sequence, it may be readily appreciated that voltages of opposite phase sequence simultaneously impressed will not result in the ideal ratio of voltmeters of 3.732, even if no harmonics are present.

The analysis of this error is too complicated to be presented in a brief discussion but the results of the analysis may be illustrated numerically. Let m be the degree of unbalance expressed by the ratio of the negative-sequence voltage to the positive-sequence voltage. This is roughly equal to the greatest deviation of any one of the three voltages from the mean. The error due to unbalance will depend not only on this ratio but on the phase angle between the two oppositely rotating components noted with reference to any instant. Accordingly the limits of the error are given in the first four lines of the tabulated illustrations below. Since the authors state that any small error due to voltage unbalance may be eliminated by stepping the line terminals around the circuit terminals and averaging the results obtained by the use of each of the three connections, a comparison of the error of this average is given also, in the last four lines.

Two numerical examples are given in the table, one corresponding to a 10 per cent unbalance such as would result from

voltages of 90, 105, and 105, or to 91.3, 100, and 108.7, each of these groups being approximately respective phase voltages which would result in a 10 per cent negative-sequence voltage, the difference in line voltages resulting in a different phase angle. The other example is based on a 1 per cent unbalance due for example to voltages of 99, 100.5 and 100.5. In general the unbalance will be between these limits, as the first corresponds to very poor service voltage while the second will be difficult to maintain even under laboratory conditions. From the figures given in the table it is seen that the results of a single pair of readings are entirely untrustworthy even with very well balanced voltages, and that good balance is necessary in order to secure reliable results, even if the terminals are stepped around. It may be noted that the average ratio is always high.

Negative-sequence Voltage m	10 Per cent	1 Per cent
Maximum ratio of readings	6.04.	3.882
Error of maximum, per cent	62	4.0
Minimum ratio of readings	2.68	3.593
Error of minimum, per cent	29	3.7
Maximum average ratio	4.022	3.7335
Error of maximum average ratio, per cent	7.8	0.043
Minimum average ratio	3.755	3.7333
Error of minimum average, per cent	0.6	0.033

The formula from which these results were calculated is included without derivation, for the sake of completeness.

Ratio of voltmeter readings

$$= \sqrt{\frac{A + \frac{m^2}{A} + 2\,m\cos(60° + \alpha)}{\frac{1}{A} + A\,m^2 + 2\,m\cos(60° - \alpha)}}$$

$$= A\sqrt{\frac{1 + \frac{m^2}{A^2} + \frac{2\,m}{A}\cos(60° + \alpha)}{1 + A^2\,m^2 + 2\,A\,m\cos(60° - \alpha)}}$$

where

A = 3.732,

m = ratio of negative - to positive-sequence components,

α = angle between components in the reference phase which is taken to be that across which the voltmeters are connected.

L. A. Doggett: We have been very pleased to have Mr. Bates attack this problem from his own angle of approach and not only check our (2 plus $\sqrt{3}$) but also show us the method of eliminating the errors due to the inductance of the voltmeters and the resistance of the condenser.

So far as the effect of unbalance is concerned we would like to submit for comparison with Mr. Bates' figures the data for one test. With balanced voltages the wave-shape factor for a certain wave was 3.693. With the same wave and with voltages of 100, 97, and 97.5, the wave-shape factors, as the terminals of the wave-shape meter were stepped around, were 3.54, 3.95, and 3.60, averaging 3.697. Experimental study of the effect of unbalanced voltages indicated that useful results were obtainable up to 2 per cent unbalance.

Mr. Smith has brought out some of the contrasts between the telephone-interference-factor meter and the present wave-shape meter. He has also covered the question of the accuracy obtainable from oscillograms. As the wave-shape meter is not a telephone-interference-factor meter, no discussion is devoted to their comparisons. Mr. Smith has described what might be called the utmost accuracy obtainable from oscillograms. The results cited in our paper are considered fair samples of every-day accuracy obtainable. As to the effect of load pulsations, we find no difficulty in getting results while undergraduate laboratory work is in full swing.

In concluding the discussion, it should be pointed out that the instrument, made accurate in the manner described by Mr. Bates, is particularly well adapted to shop testing of three-phase alternators, which have three exactly balanced voltages. Like the telephone-interference-factor meter, this meter has its distinctive characteristic. While the T. I. F. meter penalizes the 17th and 19th harmonics for 60-cycle alternators, the present wave-shape meter penalizes harmonics of phase rotation opposite to that of the fundamental.

Lastly, we find this meter admirably suited for showing and recording changes in alternator wave shape as the character of the load changes. Functioning thus, the wave-shape meter has brought to our attention some rather remarkable facts.

THEORY OF THE AUTOVALVE ARRESTER[1]

(SLEPIAN)

NEW YORK, N. Y., FEBRUARY 9, 1926

K. B. McEachron: The comparison made by Dr Slepian between the energy to be handled by the valve-type arrester and the arc-resistance type for equal protection is important. With the arc type, if the flow of system energy following the impulse is not to be excessive, it is necessary to employ considerable series resistance with the result that the arrester's ability to discharge the impulse is seriously impaired. To prevent system current from following the discharge of an impulse through an arrester, it is necessary that the voltage across the arrester, as the impulse ceases, be equal to or greater than the system crest voltage. The modern valve-type arresters are designed to operate on this principle.

In his discussion of the glow discharge Dr. Slepian states that with an electrode spacing of slightly less than 0.001 cm. a voltage of 350 volts is required to maintain the glow. The theory given states that the voltage required to start the glow is less than 400 volts and the current density in the glow is about 10 amperes per sq. cm. until the disk area is covered, after which the gap voltage increases with increasing current becoming 387½ volts with a current density of 25 amperes per sq. cm. Since the effective area inside the mica spacer is of the order of 15 sq. cm. the voltage drop across the air-gap based on Dr. Slepian's figures should be constant at 350 volts with a current of 150 amperes or less increasing to 387½ volts with a current of 375 amperes.

A series of tests covering a period of two years made on these disks have led the writer to suspect that the voltage across the air gap during a discharge was not maintained at approximately 350 volts during a discharge.

It was found, for instance, that with 280 volts (crest) applied that current would follow an impulse so timed as to strike near the crest of the 60-cycle wave. This seemed to indicate a voltage much less than 350 volts following the impulse since 280 volts was sufficient to cause current flow. With steep-wave-front impulses, applied voltages as high as 1200 volts were indicated across a single gap which showed that the breakdown might be more than three times the glow voltage.

More recently we have been able, using the cathode-ray oscillograph to determine accurately the volt-ampere characteristic of disks with spacers even when the discharge lasted but a few millionths of a second. With this oscillograph photographs have been taken showing wave fronts of less than a microsecond duration with oscillations whose frequencies were of the order of 100,000,000 cycles showing so plainly that their wave shape could be determined. With this instrument, three volt-ampere curves were taken on a stack of sixteen disks with fifteen mica spacers, each different volt-ampere curve having a different crest value of current. The disks were then coated with copper on each side and stacked up without the spacers and a volt-ampere curve taken from which the voltage drop in the disks was determined for any particular value of current. By this means it was

1. A. I. E. E. JOURNAL, January, 1926, p. 3.

found that the average resistance of a single disk was 3 ohms at 10 amperes and 2 ohms with 150 amperes flowing. With 450 amperes the average disk resistance is 1.1 ohms.

The volt-ampere curves of the air gaps for the three different currents were obtained by subtracting the disk volt-ampere curves from the disk-plus-spacer volt-ampere curves. Using Dr. Slepian's statement that with current densities less than 10 amperes per sq. cm. that the area of discharge is proportional to current it is clear that the disk voltage is constant for currents less than 150 amperes, and is numerically equal to the voltage when 150 amperes is flowing through the disk. Using this method of calculation of disk resistance the curves shown in Fig. 1 herewith were obtained. The theoretical glow voltage according to Dr. Slepian is also given. It is to be noticed that a voltage of from 600 to 700 volts was required to start current flow through the gap with the particular wave front used. As

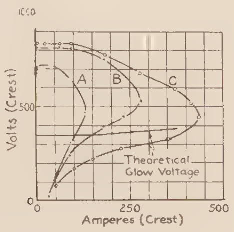

Fig. 1

the current increases to about five amperes the voltage rises to 710, 810, and 830 respectively for the three current waves. With both of the higher current curves the voltage tends to remain constant at about 800, decreasing, however, for currents in excess of about 100 amperes. When the current begins to decrease the voltage falls off until at low current values the voltage is less than 100 volts which seems to indicate the formation of an arc. It must be remembered that the shape of these curves is dependent on the amount of resistance material involved at any particular current and if the author's theory of the spreading of the discharge is incorrect then the values of resistance which have been used are not correct. The volt-ampere curve obtained across the stack of disks is a true characteristic, and the volt-ampere relations in the gap will be those given if the proper correction has been made for the resistance of the disks.

If the discharge had the characteristics attributed to it by Dr. Slepian, the voltage across the gap would be represented by 350 volts plus the additional 37½ volts as the current increased to 375 amperes. With decreasing current the relation between the voltage and the current should still be the same so that the volt-ampere curve will be represented by a single line instead of the loop which is actually found.

With all three volt-ampere curves shown, the applied voltage rose to the gap breakdown voltage in a time close to one microsecond, while the respective currents rose to their crest values in 20, 35, and 48 microseconds. From these results it would seem that the time-current relations are important in the gap discharge for with the same current, different voltages were found on each of the three different volt-ampere curves. I believe that several factors have been left out of this formula.

I have been unable to check the curves shown in Fig. 9 of this paper using this formula (corrected). I should appreciate an explanation of the formula by Dr. Slepian, and should like to know how it is plotted to get these curves.

The effect of rate of voltage application on the breakdown of the gap was not discussed by Dr. Slepian but, as with any phenomena involving ionization, time is required for the gap to reach breakdown conditions. The results of tests on sixteen disks with mica spacers are as follows:

Time-Voltage Relations of Autovalve Gap

Time to Rise to Breakdown	Gap Voltage (Crest)
1.5 microseconds	665 volts
2.5 "	530 "
30 "	390 "
60 cycles	400 " variable

These results show that in discussing the characteristics of the discharge between two electrodes as in the autovalve gap, the effect of time both before the discharge begins and after it has started cannot be neglected.

The test results given in this discussion show that discharges having quite different volt-ampere characteristics from those given by Dr. Slepian are actually to be found in the air gap between autovalve disks. These results are useful not only in connection with the theory of the glow discharge but also are of importance when applied to the actual arrester performance in service. So far as I know these results are the first to be actually obtained under impulse conditions where the time, voltage, and current relations are fully determined.

On the sixth page Dr. Slepian gives a formula for the determination of the temperature rise at the surface of a disk when a certain amount of energy is liberated at the disk surface.

J. Slepian: The paper which I have presented was written over a year ago, and in that time there have been some important additions to our knowledge of the theory of the autovalve arrester which I would like to mention briefly before taking up Mr. McEachron's welcome account of his researches.

The autovalve arrester in its functioning depends on the well established fact that a heavy current discharge between electrodes of resistivity of the order of ten ohms per cu. cm. remains in a high-voltage form for a relatively long time, whereas such a discharge between metal electrodes changes into a low-voltage form within less than a microsecond after its initiation. These two forms of discharge have long been known as glow and arc, respectively, and their properties, at least in the steady state, are fairly well known. As stated in the paper, it is generally believed that the arc discharge takes place when the cathode is hot enough for thermionic emission. Then, a difficulty arises because it appears that the density of energy input into a metal cathode surface from a glow is not great enough to heat a spot on the electrode to a high temperature in a time so short as a microsecond. It seems necessary to assume almost immediate convergence of current into some spot before that spot has become hot. The resistivity of the autovalve electrodes opposes this concentrating tendency.

Until recently, it was assumed that this concentration of current took place at inhomogeneities of the metal surface. Now, however, a new theory has been developed which seems to fit the facts quantitatively, and eliminates the need for inhomogeneities to start the current concentration. This theory is that in the heavy-current glow discharge at atmospheric pressure, the air immediately adjacent to the cathode becomes heated almost immediately to a temperature high enough for thermal ionization, and with metal electrodes this thermal ionization causes the glow to be unstable and to converge into an arc. Further particulars may be found in a paper which appeared in the *Journal* of the Franklin Institute for January, 1926.

Another advance which has been made is in our understanding of the factors which determine the rate of spreading of the discharge in the autovalve gap from its point of initial breakdown next to the mica spacer. We have known, from our tests on the protective valve of the arrester, that this spreading is very rapid, but now we have information as to the influence of electrode spacing, and also know how this factor influences the volt-ampere characteristic for impulse voltages.

The points of lowest breakdown in the autovalve gap are next to the mica spacer, the breakdown voltage there being usually less than 400 volts. If the mica spacer were not there,

the breakdown voltage would be much higher, depending on the width of the gap, and for a 5-mil gap would be about 1000 volts. Now it is clear, that with such a 5-mil autovalve gap, if 1000 volts is applied, the discharge does not need to start at the mica, but the gap will break down at all points together. For such a voltage then, the discharge may be said to spread instantly over the electrode surfaces. For a lower voltage the rate of spreading while still very fast will no longer be instantaneous. Since the rate of spreading of the discharge determines the rate at which

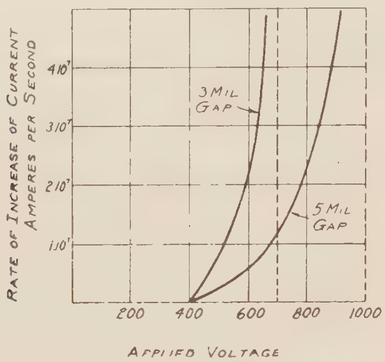

Fig. 2

the discharge current builds up in the arrester, we may expect a curve such as in Fig. 2 herewith, with an asymptote at 1000 volts for the 5-mil gap. For a 3-mil gap the asymptote will be at about 700 volts.

When an impulse current is sent through an autovalve gap, the total voltage while the current is increasing is determined by the rate at which the current is increasing. If the current is increasing slowly, the voltage will be about 400, but if the current builds up instantly the total voltage may be 1000 for

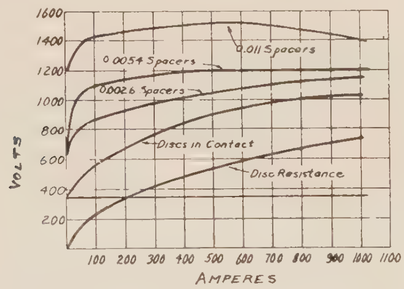

Fig. 3

the 5-mil gap and 700 for the 3-mil gap. The total voltage here includes not only the discharge voltage but also the resistance drop through the disks.

These ideas are largely the result of a study by G. F. Harrington of the impulse volt-ampere characteristics of arresters with different sizes of spacers. These were taken by determining the maximum volts and maximum amperes in a discharge by means of sphere gaps. Fig. 3 shows results obtained. It is evident that with the disks in contact, the voltage obtained corresponds to the steady-state glow, but that when the disks are separated, there is an additional rise in voltage which is necessary to cause the discharge to spread sufficiently rapidly over the disk faces.

The lowest curve in Fig. 3 is the impulse volt-ampere curve of the disk resistance, obtained by copper-plating both faces of each disk and stacking them in series. On subtracting this curve from the others in Fig. 3 we get the curves of Fig. 4. Disks in contact give a curve which lies very close to the 350-volt line, but with increasing thickness of spacer, the voltage on impulsive discharge increases rapidly.

Coming now to the results which Mr. McEachron has obtained with the cathode-ray oscillograph and which are shown in his Fig. 1, we see that as regards the magnitudes of the voltage for increasing current, there is general agreement with the results obtained by Harrington and shown in Figs. 2 and 3. It would seem from these curves that Mr. McEachron used spacers at least 0.005 in. thick, which is the upper limit for spacer thickness tolerated in the commercial autovalve arrester. With thinner spacers even better performance would be obtained. However, I believe that because of the incorrect value which he has taken for the ohmic drop through the disks, the lower parts of Mr. McEachron's curves are in error.

First of all, the current density in the discharge is only approximately 10 amperes per sq. cm., and may actually be somewhat larger. It is probably also not an absolute constant, and may vary with slight changes in disk composition. But

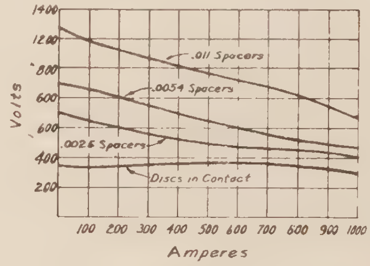

Fig. 4

taking this value, although the whole disk area is not uniformly covered for current less than 150 amperes, when the current decreases to less than this value, the discharge breaks up into a large number of very small spots which are distributed over the whole face of the disk. With this distribution of discharge the ohmic resistance is that of the whole disk and not that of only part of the disk as Mr. McEachron figured. Therefore I have redrawn Mr. McEachron's curves with the correct ohmic drop in Fig. 5.

These curves show three more or less distinct portions—first there is a higher voltage part where the current is spreading over the disk face. Then comes a drop to approximately 350

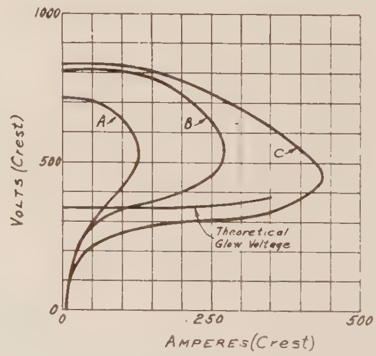

Fig. 5

volts, where the curve tends to become horizontal. The slight departure from 350 volts is readily accounted for due to uncertainty in the disk resistance, since the current distribution in plated disks is different from that with discharge, and also uncertainty in the proper value to take for the current density. Lastly there is a low-voltage part during the last 50 amperes of the discharge, which is undoubtedly due to vague contacts and lining up of particles in the gap by the intense field.

These vague contacts which follow an intense discharge explain Mr. McEachron's finding a current flow at 280 volts. By raising the resistivity of the disks this leakage current may be

reduced to as small a value as we please. In the commercial autovalve arrester this leakage is usually not detectable on an ordinary oscillograph.

Mr. McEachron's experiments on the impulse breakdown of autovalve gaps are very interesting. They show that the voltage rises to less than double for very fast discharges. When the voltage reaches the value corresponding to the gap length without distortion due to the spacer, we should expect speeds equal to that of a sphere gap.

The last point which Mr. McEachron raises is as to the correctness of Fig. 9 in the paper. The formula is incorrectly printed and should read,

$$T = \frac{W \sqrt{t}}{4.18 \sqrt{\pi\, k\, c\, \delta}}$$

Taking $t = 0.001$ sec., $k = 0.016$, $\delta = 2.0$, $c = 0.185$ and $W = 3500$, gives $T = 194$ deg. which agrees with the curve of Fig. 9.

IONIZATION STUDIES IN PAPER-INSULATED CABLES—I[1]

(Dawes and Hoover)

New York, N. Y., February 8, 1926

A. E. Kennelly: Turning to the paper by Dawes and Hoover, it seems to me that the great force of that contribution lies in the fact that a bridge has been developed which employs a vibration galvanometer, with all the delicacy and precision that the vibration galvanometer affords, so that instead of having to employ a relatively great length of cable dielectric for test, it is sufficient to have only, say, a couple of meters, provided that the particular couple of meters shall represent fairly well, the whole length of a cable under consideration.

E. W. Davis: One of the most important problems which confronts the manufacturer of high-voltage cables is that of dielectric loss, its fundamental cause and its relation to the other necessary properties of a well designed cable.

The papers by Messrs. Dawes & Hoover adds one more to the numerous theories concerning the nature of dielectric loss and power factor. Unfortunately many of the papers published to date, while excellent mathematical treatises on the subject, are not founded on any scientific research work or based on data of many tests. In fact, outside of a very few isolated experiments, many of the theories cannot be checked at all.

In a recent paper presented before the British Institution of Electrical Engineers, "Dielectric Problems of High-Voltage Cable", by Percy Dunsheath, an attempt is made to connect dielectric loss with dielectric absorption, dielectric hysterisis, and dielectric conduction. Much data and many curves are given to substantiate the theory and there is included a rather unique discussion of the relation between a-c. and d-c. losses.

The paper by Dunsheath and the paper by Dawes & Hoover offer two widely divergent theories for dielectric loss, and yet both of them contain features that may be readily checked.

Fig. 1 herewith shows a few typical power factor-voltage curves that we have obtained with various impregnating compounds and at various temperatures. These tests were made in a special oil testing condenser and with a high-voltage, 60-cycle bridge. The curves are quite similar to those shown in the Dawes-Hoover paper, one in particular showing the peculiar knee found at high temperatures by these investigators.

Fig. 2 shows two curves calculated by means of the formula (17) of the Dawes & Hoover paper. By slightly varying the assumptions as to location and dimensions of the air films, both types of curves are obtained. One interpretation of such tests would indicate that compound ordinarily contains more or less air distributed through it and exhibits the same phenomena of restricted ionization as laminated insulation even though the barrier effect of the paper is not present. Another phenomenon exhibited by cable insulation, but not discussed by Dawes & Hoover, is the V curve of power factor and voltage. Numerous samples tested show a decrease of power factor with increasing voltage and then as higher stresses are reached, a rapid increase.

In built-up insulation, there are invariably minute air films. The loss through these films depends upon the conduction

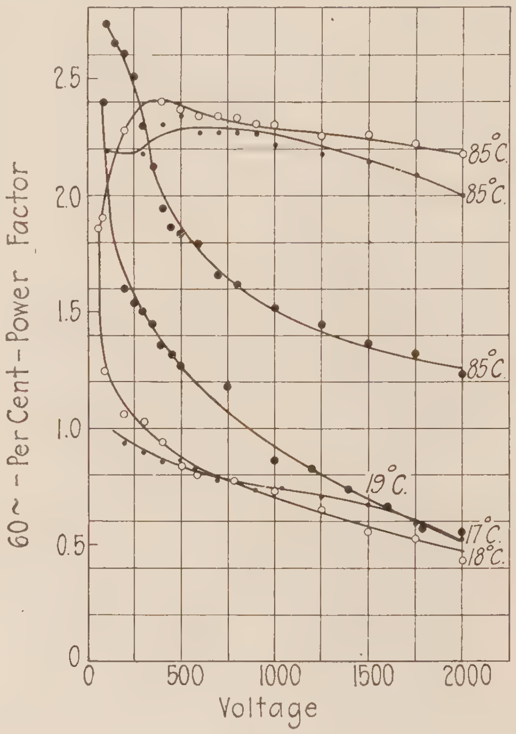

Fig. 1—Power Factor Versus Voltage Various Impregnating Compounds

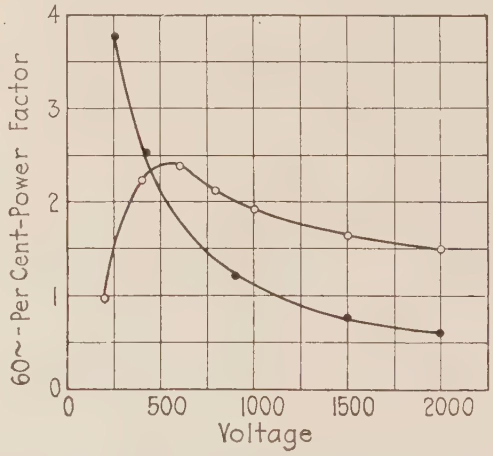

Fig. 2—Calculated Power Factor-Voltage Curves Impregnating Compounds

through and conduction around the film along the paper. The conduction loss at low stresses would follow ohm's law and at high voltages would depend upon the degree of ionic saturation or ionization. If we consider a very low-pressure air film between two paper tapes, the full ionic saturation would be reached at a very low stress and, therefore, the leakage current would not increase directly with the voltage. The dielectric loss, therefore, would not increase directly with the voltage and this would mean a decrease of power factor with increasing stress. This phenomenon holds until a point is reached where ionization

1. A. I. E. E. Journal, April, 1926, p. 337.

of the higher-pressure air in the insulation is complete. If the ionization took place at the same voltage for a large majority of the air films, we would expect a sharp increase of power factor. It is possible that the ionization point for various films may differ so much that a gradual rather than a sharp increase of power factor occurs. This effect is of course governed by the relative amount of air to insulation, the average pressure of these air films and the leakage characteristic of the paper insulation. We should not expect to find this phenomenon in a cable the paper insulation of which had quite high leakage characteristics.

Tests on Impregnated-Paper Sheets. Power-factor tests on sheets of vacuum-dried and impregnated paper were made with a high-voltage bridge in order to check the previous conclusions. It was thought that tests on single sheets of paper in very close contact with the electrodes would show the characteristics of the paper insulation itself. Then, using more than one sheet, tests could be made with air films between.

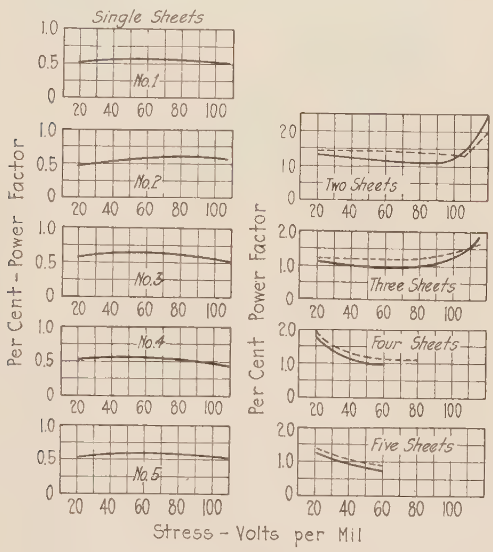

Fig. 3—Sixty-Cycle Power Factor Versus Voltage Impregnated-Paper Sheets. Dotted Curves are Results of Tests with Pressure on Upper Electrode

The curves in Fig. 3 show the results of these tests.

In no instance was a *V* curve obtained with a single sheet of paper. Two and three sheets of paper, when placed loosely together and tested, gave decided *V* curves of both the gradual and the sharp type. With three and four sheets of paper, sufficient stress could not be obtained with the voltage available to reach the critical point in the power-factor curve but the start of the *V* curve was obtained in each instance. The application of pressure to the upper electrode when testing multiple sheets changes the character of the curves very much. In Fig. 3, when two sheets are tested under pressure, the *V* curve is partially eliminated and the voltage at which ionization takes place is increased. With three sheets under pressure, the *V* curve is eliminated completely. In the case of four and five sheets, sufficient pressure was not applied to remove the *V* curve completely but the dotted curves shown seem to indicate the tendency for this to take place.

W. A. Del Mar: The paper by Dawes and Hoover contains a wealth of experimental material which requires considerable detailed study, and it is difficult to comment upon the results without knowing more about the materials worked upon. For instance, cables impregnated with different types of compounds would probably show different characteristic curves. I think that the value of the paper would be increased very much if information were given regarding the type of compound used in the cables for which curves are given. For instance, whether the compounds are solid or liquid at the temperatures at which the experiments were made, and so on.

I notice that most of the experiments, if not all of them, were made with single-conductor cables. Some rather interesting work which Mr. Hanson has been doing and also some which has been done in England and recorded in the current Journal of the Institution of Electrical Engineers, England, indicates that in three-conductor cables, a large proportion of the loss which occurs at the higher voltages occurs in the fillers, and if the fillers are omitted or replaced by some material which has not the same characteristics as the ordinary paper crepe, those losses can practically be eliminated and the ionization curve,—that is to say, the voltage-power factor curve,—becomes virtually a horizontal line between stresses of 20 volts and 100 volts per mil, which are about the limits in Fig. 5 of the paper.

It would therefore seem that the work which the authors have done needs to be somewhat amplified by an analysis of just the parts of the cable in which the principal losses occur, at the different voltages. It is possible that by such an analysis, steps could be taken to reduce these losses at the higher voltages.

Anyone who has done any laboratory work of this kind will appreciate the immense amount of painstaking, careful work that Prof. Dawes and Mr. Hoover have done in this paper. Nevertheless, I am not entirely convinced that their curves represent insulation characteristics to the exclusion of test-apparatus idiosyncrasies. When, however, you look at the curves and compute the number of experimental points they have made, the work appears to be really prodigious, and even if some corrections should have to be made, the authors are to be congratulated upon their results.

R. W. Atkinson: I have been interested in bridge measurements ever since I became connected with the cable industry, and last year published in the *Electric Journal* a description of the method we are now using and gave a brief description of it in a discussion before the Institute. The bridge that has been shown tonight, and the one I described are about as different in general construction and circuit as two instruments both of the bridge type could well be and yet serve the same purpose. Yet I am interested to note that they both have certain fundamental characteristics and attain final results equivalent in many respects.

The sensitivity of the two types is nearly the same, so far as I can judge from the figures given in the paper, and the voltage across the measuring parts of the bridges is comparable. These are fundamental parts of the whole problem of precision measurements of dielectric losses. As Prof. Dawes has pointed out, it is very desirable indeed to have the voltage drop across the resistance in series with the measured condenser very low so that no difficulty will be experienced from the effects of the capacitance to ground of the detector and certain other parts of the circuit. His instrument and mine are closely alike in this respect and have a very much lower drop than in the case of any other dielectric-loss-measuring device of comparable sensitivity that has been described.

Some fundamental differences between the two bridges are these:—My bridge uses an a-c. galvanometer as a detector; Prof. Dawes uses a vibration galvanometer with vacuum-tube amplifiers to get the same result.

The vibration galvanometer requires accurate frequency which is not always convenient where a commercial circuit supplies the power. The a-c. galvanometer requires an auxiliary source of current to supply the field at the same frequency as that supplying the measured condenser.

An advantage of our bridge over most other devices for measuring dielectric loss is that it is so arranged that when balance is obtained, the power factor may be read directly from the dials.

There is one difference between the two instruments, which is a very important one and is in favor of the a-c. galvanometer

type. In using the vibration galvanometer, it is necessary to secure a very accurate capacity balance before the power-factor balance can be obtained. With the a-c. galvanometer type the bridge is first made sensitive almost entirely to capacity and then made sensitive almost entirely to the power factor, by changing the relation of the field so that the capacity balance does not have to be made nearly so accurately as it would otherwise have to be. This is very significant because it permits measurements to be made much more rapidly than with the other type.

E. S. Lee: With reference to the Dawes-Hoover paper, I think there are several things of great interest to those who have to work with cables and make measurements thereon. In the first place, we find that we have one more method added to the already long list and large number of different means by which we measure dielectric power loss. This is a bridge method. As Mr. Atkinson has said, about a year ago he described his bridge, and just a year ago from this same platform we were told of work which had been done with the Schering bridge, which work has been carried on for this past year with great success.

Prof. Dawes says: "On one occasion after completing a 60-cycle test, we found that the 25-cycle losses were greater than the 60-cycle losses even though sufficient time had been allowed for the cable to reach constant conditions." Such conditions are not new to those who are making these measurements continually. Also, if you will observe the curves of his Figs. 11, 13, and 16 you will observe "humps" which might be looked upon as indication of error. But Prof. Dawes has stated that they have checked those portions and they find those humps should be there in the curves. These also are found by other observers.

Thus, we are glad to find that as new investigators take up this work, their results are in agreement with what has been found in factory testing and experimentation.

I want to call attention to one point, which may not be necessary, particularly to those who are familiar with the work, but I think it is quite necessary, particularly for those who are not so familiar with the work. Some reference was made to the fact that these are characteristic curves, and I grant you that they are, except I would call to your attention that the largest portion of these curves is outside of the operating range; that is, the curves in Figs. 8 to 16 are for a cable which we would say would be normally rated at 12 kv. If you will look along the abscissas or on the curves for 12 kv., you will notice that within that value the dielectric power loss is quite small; the power factor is very low, and the change in these values is small. It is well beyond this voltage that the changes occur. In the present-day cable, the same conditions exist. We have to go beyond the operating values, considerably, in order to get these changes.

There is one other thing to which I would like to call attention; when I first looked at these curves, I thought the change in capacitance was enormous, but if you will note the scales, you will find it is not. It is only about 5 per cent. The change in the power factor is of the order of 300 to 400 per cent, the change in dielectric power loss is of the order of about 3000 per cent. So one has to observe these scales carefully in order to obtain correct conceptions. The explanation offered by the authors for the shape of these curves is good and of value, though if tests are made on cables with different treating compounds and with liquid fillers, it will be found that these same curves are not characteristic for those cables but that another set of characteristic curves will be obtained. Their shape likewise has to be explained.

I believe we are largely forgetting what power factor is. We talk about it quite a bit. I believe I am right when I say that it is the ratio between the dielectric power loss and the product of the voltage and the current. In other words, the variations in these three quantities govern the variation of the power factor; therefore, a discussion of the variation of power factor must include the variation of these factors. It is really the dielectric power loss that we are interested in. If we talk in terms of power factor, then our results become more directly comparable without regard to volume of the dielectric, but I think if we remember that the loss varies quite nearly as the square of the voltage, that the capacitance does not change greatly, hence current is proportional to voltage, we can work out the ratio of these factors and see just about how the power factor will vary. If air ionization is present, however, conditions are quite different from those when no ionization exists, particularly since the dielectric power loss varies at a faster rate than the square of the voltage.

I was interested in the agreement between calculated results and measured results, and the statement also that if we knew the constants, we could very readily calculate. I think that is true but the constants are often difficult to determine.

W. B. Kouwenhoven: The authors state that the air condenser that they employed in their bridge had a phase angle. In measurements that I have made with the Schering bridge I have never been able to detect any phase angle in the air condenser used. Slight errors, however, may creep in due to insufficient shielding of the leads and apparatus, and these will cause discrepancies which are usually assigned to a phase angle in the air condenser. Proper shielding will often eliminate these errors.

In some work that I have been doing with Dr. Whitehead

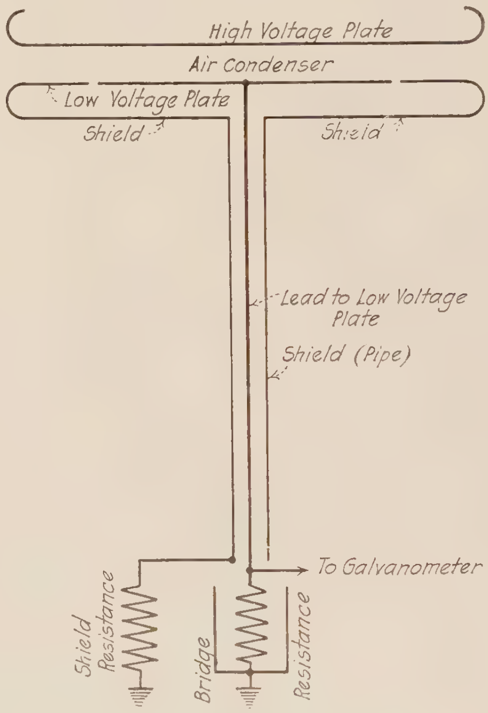

FIG. 4

we have found it necessary to shield the air condenser and its leads as shown in Fig. 4 herewith, which shows the air condenser side of a high-voltage bridge. The pipe shield on the lead to the low-voltage plate of the air condenser must be maintained at the same voltage as the lead otherwise charging currents between this lead and its shield will introduce errors in the results. Any change that is made in the bridge resistance in series with the condenser lead must be accompanied by a proportional change in the resistance in series with the shield, otherwise an error will be produced in the phase angle as determined in the bridge. The shielding of the specimens should be carried out in a similar manner.

In measuring losses at high voltages with the Schering bridge

or with the quadrant electrometer at Johns Hopkins University we have followed the practise of determining the accuracy of the apparatus. In making this check we first measure the loss in a specimen and then insert a known non-inductive resistance in series with the specimen and measure the loss again. We determine the current in the specimen circuit and calculate the loss in the added resistance. If the apparatus is functioning correctly the loss in the added resistance should equal the difference between the first and second loss measurements.

W. F. Davidson: I desire to call attention to certain limitations of the method used by Dawes and Hoover and, indeed, by most other investigators. We are dealing here with a composite insulation which is stressed to such values that ionization reaches considerable proportions. As a consequence, such "constants" as capacity and resistance cease to be true constants and not only vary with the effective value of the impressed voltage but even vary cyclically. Whitehead, Peek, and others have called attention to the distorted current wave of corona, which is merely another way of stating that the capacity and resistance are not constant.

Under these conditions the observed data, and with them the computed data, will depend upon the method of measurement—a wattmeter method will give one result and bridge methods other results.

To illustrate this, assume that the impressed voltage is not distorted in any way and that we have a reference "no-loss" circuit as well as the circuit containing the test specimen. The voltage and the two currents may be written in the form:

$$e = E\,[A_1 \sin \omega t + B_1 \cos \omega t]$$

$$i_1 = I_1\,[a_1 \sin \omega t + b_1 \cos \omega t]$$

$$i_2 = I_2\,[\alpha_2 \sin \omega t + \beta_2 \cos \omega t + \ldots \alpha_n \sin n \omega t + \beta_n \cos n \omega t]$$

and

$$A_1^3 + B_1^2 = 1, \quad a_1^2 + b_1^2 = 1, \quad \alpha_2^2 + \beta_2^2 + \ldots \alpha_n^2 + \beta_n^2 = 1$$

In the test circuit the true power will be

$$W = \frac{E\,I_2}{2}\,(A_1\,\alpha_2 + B_1\,\beta_2)$$

since the over-tones in the current wave have no corresponding element in the voltage wave and hence do not contribute toward the average power.

If the measurements be made with a wattmeter (dynamometer or electrostatic) with an ammeter and voltmeter, the observed and computed results will be:

Potential difference $= E/\sqrt{2}$ r. m. s. volts

Current $= I_2/\sqrt{2}$ r. m. s. amperes

Power $= \dfrac{E\,I_2}{2}\,(A_1\,\alpha_2 + B_1\,\beta_2)$ watts

Power factor $= A_1\,\alpha_2 + B_1\,\beta_2$

Resistance $= \dfrac{E}{I_2}\,(A_1\,\alpha_2 + B_1\,\beta_2)$

Capacity $= \dfrac{I_2}{E\,\omega\,\sqrt{1 - (A_1\,\alpha_2 + B_1\,\beta_2)^2}}$

If the measurements be made with a bridge using a tuned vibration galvanometer or a dynamometer with fields excited at the fundamental frequency, the results would be as follows if the measured voltage and standard capacity are used:

Potential difference $= E/\sqrt{2}$ r. m. s. volts

Current $= \dfrac{I_2}{\sqrt{2}}\,\sqrt{\alpha_2^2 + \beta_2^2}$

Power $= \dfrac{E\,I_2}{2}\,(A_1\,\alpha_2 + B_1\,\beta_2)$

Power factor $= \dfrac{A_2\,\alpha_2 + B_1\,\beta_2}{\sqrt{\alpha_2^2 + \beta_2^2}}$

Resistance $= \dfrac{E}{I_2}\;\dfrac{A_1\,\alpha_2 + B_1\,\beta_2}{\sqrt{\alpha_2^2 + \beta_2^2}}$

Capacity $= \dfrac{I_2\,(\alpha_2^2 + \beta_2^2)}{E\,\omega\,.\,\sqrt{(\alpha_2^2 + \beta_2^2) - (A_1\,\alpha_2 + B_1\,\beta_2)^2}}$

These results depend on the fact that the bridge will only balance the fundamental component of i_2 against the reference circuit. In a bridge measurement, securing balance with a hot-wire or other untuned detector, it will be impossible to secure an exact balance and the observed values will differ in many points from those above.

In closing, I should like to suggest that we have reached a point in our researches where it seems essential that we consider instantaneous value $\dfrac{\partial E}{\partial I}$ and not average values. Fortunately the means for doing this are already at our disposal in the cathode-ray oscillograph. The JOURNAL of the Institution of Electrical Engineers for November, 1925, contains three excellent papers dealing with this powerful tool of the modern investigator into dielectric phenomena.

G. B. Shanklin: Several years ago I made a special study of the subject of "ionization in cables," and as a co-author submitted some of the findings in Institute papers. Our work dealt largely with "cause and effect" from a practical standpoint. No quantitative nor qualitative analysis was attempted. The work, in conjunction with that of contemporary workers, resulted in recognition of the cause and importance of ionization in cables and established methods of eliminating or reducing it. Recent advancement in the voltage rating of cables is based on the principles demonstrated by this early work.

A more expert and systematic study by qualified physicists and research engineers familiar with the electron theory has long been needed. This excellent paper by Messrs. Dawes and Hoover represents, I hope, a beginning which will result in eventually establishing the theory of ionization in cables on a firm quantitative basis.

Their present results are not only a distinct advancement but are in good agreement with our previous work, as far as it went. By using a length of ordinary impregnated paper cable with a special loose sheath, we obtained curves very similar to those in Fig. 7 of the paper. The curves were not, as theirs are, subject to accurate analysis, for ionization of the large air space directly under the loose sheath was obscured by simultaneous ionization through the thickness of paper insulation. The use of a model cable sample enabled them to obtain much more accurate data.

Change or shifting of ionization curves, as shown in Fig. 9, is, as they state, a function of time. I agree that residual or free ions, after the voltage is reduced, are the main contributing cause of this, but do not agree that absorption or higher internal temperature plays an important part. Instead, there appears to be a factor discovered by J. J. Thomson and called "ionization pressure," which is important. When the gas spaces are first ionized, this "ionization pressure" pushes the softened compound back, resulting either temporarily or permanently in enlarged gas spaces. A particular cable might operate indefinitely at normal voltage without ionization, but if a momentary over-voltage, such as produced by a switching surge is applied, ionization might persist for some time after the voltage drops back to normal. This is, in effect, exactly the same characteristic shown in Fig. 9.

The irregular shape of the first section of the high temperature-power factor curves, as shown by Figs. 11 and 13, is, I have believed for some time, due to the liquid nature of the compound. Some form of ionic conduction through this liquid is apparently responsible, for these peculiar shapes are obtained only with liquid filling compounds. I have seen the same type of curves obtained at room temperature when a thin oil is used for impregnation.

On the fourteenth page the authors make the statement: "It has been recognized for some time past that, although the paper itself has lower dielectric strength than the impregnating compound, the dielectric strength of the cable is increased by using paper in combination with compound." This statement is misleading. They evidently mean that cellulose fiber in paper form and in combination with air has less strength than when in combination with compound. This is evident since compound has greater strength than air. Actually, cellulose in pure form is an excellent insulator, and this is why paper, acting as a barrier, improves the dielectric strength of the compound.

Their theory of the formation of tree designs seems very plausible. Certainly, it must be due to tangential stresses along and between the surfaces of the paper wrappings. The high-frequency nature of this discharge is also well established. It might be pointed out that impregnated paper insulation has something like one-tenth the dielectric strength longitudinally between surfaces of wrappings, that it has radially or perpendicular to these surfaces. The absence of fiber barriers in this direction accounts for this.

It is sincerely hoped that the authors will continue their valuable work to a final conclusion.

J. B. Whitehead: We have had some difficulties which Professor Dawes doesn't mention, and which I hope he hasn't had. There are also some that he has had which we have not. Dr. Kouwenhoven has called attention to one of our greatest difficulties, that is, the screening of the test electrode and maintaining the guard electrode at exactly the same potential. On our Schering bridge, we found we could get power-factor measurements in the same range that Professor Dawes is working, that would differ by 50 to 100 per cent simply by a variation in the resistance in the tail of the guard circuit. I presume he has solved that difficulty, or perhaps his bridge is not so sensitive to it as our own.

As to the phase difference of his air condenser, I am astonished at the value that he finds. We have found nothing to indicate such a difference in our condenser. We have split it into two halves, put one-half in each side of the bridge, and have added small resistances in the tail circuit of the side we are measuring, thus checking by successive increments of power factor, to see whether there is any initial value of phase difference. We have not detected any, and I hope that Professor Dawes, will tell us what he consideres to be the source or cause of the phase difference he finds. In this connection I have the following references to phase difference in air condensers:

Giebe and Zickner, in the Archive fur Elektrotechnik, find that in standard air condensers of the Reichsanstalt no phase difference can be detected by methods measuring the same to an accuracy of from one to two seconds of arc. These are small air condensers, and I think the maximum voltage upon them was about 300 volts, and the measurements were directed only at the possibility of a phase difference due to the normal ionization of the air. This is the only source that I can think of for a phase difference, unless, one has actual point discharges between the plates of the condenser, in which case you could get ionization losses of any description. I assume that Professor Dawes' condenser was free from error of this type.

E. Möller also finds that radium rays and copious brush discharge in the neighborhood of an air condenser have no effect on its phase difference, but he is working at frequencies up to 180,000 and above, so perhaps his figures cannot be taken.

C. H. Willis who is working in my laboratory has computed the value of the phase difference due to the normal ionization in the air. This was for a condenser of our dimensions, in which the space separation up to about 35,000 or 40,000 volts is two inches. The ratio of charging current to conduction current is based on the normal velocity of ions in the air, and the potential gradient and the frequency, and so on, a very simple calculation. The value of the phase difference in this case works out to be 4×10^{-6}. This is far below the figures which Messrs. Dawes and Hoover have given and indicates a negligible phase difference.

I do not feel that it is necessary to invoke the structure of the atom in explanation of the behavior of this type of insulation. I believe that the change in the power factor, as it rises beyond the ionization point, can be accounted for by the saturated conditions in these air layers, if it be remembered that this ionization is extinguished at every half wave, as the voltage goes down below the critical value. We have every reason to suppose that at such frequencies as we are using here, there is complete extinction, every half wave. As a consequence there arises the question of the recombination of the ions, and I think it is clearly evident from the very interesting and beautiful experiments on the artificial cable with an air layer, that there is a normal saturated condition due to a limited air area, beyond which you do not get any further ionization and therefore no further loss, as you go on up in voltage.

Another thing that we have to note here is that there are two possible sources of loss in ionization: one due to the actual process of ionization itself, the actual collision or the knocking apart of component parts, and then on top of that such conductivity as exists due to the passage of the ions across the air space. I think it is very easy to picture a saturated condition and if we have that, it is very easy to see that as the voltage curve goes up, the power factor may reach a maximum.

I also was particularly interested in the difference between the ascending and descending curves, and I would like to ask whether these curves repeat themselves accurately. Nothing has been said here about the effect of the presence of ionization on the cable structure itself. It is a most powerful destructive agent. If you have any layer in which there is active ionization going on, I wouldn't say that it would remain in the same condition for more than a few seconds. I think it probable that much of the trouble in cable insulation is due to the fact that it is rapidly destroyed as soon as we let ionization start. I venture the prediction that in a few years' time we are going to see some curves of this kind which will be flat, and when you do that, and not until you do, will you have cable that will be satisfactory. When ionization goes on, the cable is going to pieces, and it seems to me that it is only a question of thorough and complete impregnation. If we can get that, I don't see how we can fail to straighten these curves out and get rid of the principal cause of this trouble.

C. A. Adams: Referring to the destructive effect of internal corona, I have photomicrographs which show the fusing by corona of mica laminae in the insulation of a 25,000-kv-a. turbo alternator. There was in this case conclusive evidence of what might be called a "corona blast," namely the reaction of the corona currents on the magnetic field due to the load currents in the armature conductors; the corona current being perpendicular to the magnetic field.

C. L. Dawes: Mr. Del Mar requested some more data on the cable. These are in the hands of the Committee. We have the cable numbered and I believe we know the manufacturer, but we we do not know the compound. He states that he hopes we determine in which part of the cable the loss occurs. At the present time we are analyzing the cable layer by layer, finite thicknesses from the center out, those thicknesses being so small that they are practically surfaces. Our one source of error is that we must assume that the air spaces are equally distributed through the insulation. If that is not true, our work obviously will be in error.

He states that we have done a lot of work and determined so many experimental points. I merely wish to add to that and state that these are just a few representative data. There wouldn't be room in an ordinary journal to include all the curves which we could put in.

We are very glad Mr. Lee pointed out the fact that we were

carrying the operating range of the cable above the ordinary operating voltage. It is necessary to do this, however, in order to study the phenomena. We are studying ionization itself, and we are not attempting to obtain the ordinary commercial curves which have been published or which are readily obtainable in many manufacturers' laboratories.

Mr. Davidson brought out the fact that the current is distorted by the variable factors in the circuit. We have had that in mind for some time, and Mr. Hoover and I have discussed the possibility of obtaining oscillograms of the charging current through the cable. That is one of the details which we have set aside until a more opportune time comes to make an investigation in that particular direction. I will state, however, that in some of our early experiments the man who was doing the work at that time told me that he had obtained a power factor of something like 0.1 per cent. I questioned it very much, and on further investigation I found that he was using as a source the commercial lighting circuit, and he had not become familiar with the galvanometer, and inadvertently he tuned in for the third harmonic; in other words, he was balancing up the third harmonic and in his calculations he obtained a power factor which was one-third of what he should have obtained.

P. L. Hoover: I will reply first to Mr. Atkinson's statement that in balancing a bridge "it is necessary to secure a very accurate capacity balance before the power-factor balance can be obtained." It can be shown mathematically that this effect is inherent in the bridge and does not depend on the type of measuring instrument used. Furthermore, with the Wien and Schering bridges it can also be shown that the power factor, as determined by a minimum deflection of the detecting instrument, may be in error by 50 or 100 per cent if the capacity balance is out by about one per cent. This effect does not enter in the bridge used for this investigation. With this new bridge an accurate capacity balance can not be obtained if the power-factor balance is out very far. The two balances must be obtained simultaneously.

Furthermore, an amplifier is not necessary with this bridge although it helps considerably at the lower voltages if the sample is small. At higher voltages, above 25 kv., the amplifier is not used.

The question raised by Professors Kouwenhoven and Whitehead concerning the grounding of the condenser shield through a resistance is interesting in that it points out another advantage of this new bridge over the Wien and Schering bridges. Since, with the latter bridges, it is necessary to make the capacity balance to extraordinary precision in order to get a fair precision in the power-factor balance, it is essential to maintain the guard ring or shield at exactly the same potential as the low-voltage electrode of the condenser. Otherwise the effective capacity of the condenser will change due to the change in the potential distribution within the condenser. This effect is largely eliminated in this new bridge since the power-factor balance does not depend upon such a critical balance of the capacitances.

It should also be noted that the resistance in the shield circuit is not a constant, neither is it equal to the resistance in the other arms of the bridge. If C_1 and C_2 represent the capacitances of the low-voltage electrode and the shield respectively, and R_1 and R_2 the resistances in series with these capacitances, then, for the shield to be at the same potential as the low-voltage electrode the shield resistance must be $R_1 = R_2 (C_1 \; C_2)$. Consequently the resistance in the shield must be changed every time the bridge is changed. With the Wien and Schering bridges this effect is very important and accounts for Prof. Whitehead's observation that a small change in the shield resistance may change the power factor by 50 to 100 per cent.

Check measurements made since the writing of this paper have shown that the angle of our air condenser was due to insufficient shielding of the lead from the low-voltage electrode of our air condenser as Prof. Kouwenhoven has pointed out. In our particular case there was magnetic coupling as well as electrostatic. Shielding corrected the difficulty and our air condenser now has no measurable loss.

ILLUMINATION ITEMS

By Committee on Production and Application of Light

THE LIGHT-COLOR PLAYER*

If, by a person seated at an instrument, illumination could be as flexibly and delicately controlled as sound can be by one seated at a piano, is it not conceivable that we should have a new method of emotional expression which might ultimately become a rival to music, or at least a valuable and glorious accompaniment to it?

While the main problem involved in designing such an instrument has always been the flexible and continuous grading of the intensity of illumination from darkness to its highest pitch, and vice versa, of course the problem of color-play at once assumed its interactive importance. Color is so wonderful a phenomenon in the act of seeing that it could not be ignored in the attempt to express emotion through the sense of vision; such a source of highly pleasurable sensations must be taken advantage of. And yet the injection of color-play has tended, in the popular mind, to obscure the full appreciation of what light-play is.

Through long association with lighting effects on the stage, or by watching moving picture screens, one naturally thinks of color-play on screen or stage, as being something at which an audience would sit and look. It is true that colors may be most beautifully presented when thrown on a monochromatically reflecting screen—preferably a white silvered curtain, hanging in loose folds. And it may be that while color-play on such a curtain, or on other objects or surfaces of a stage, will constitute an important feature of this new art, yet, after all, this is but a fraction of its main object. To produce its maximum emotional effect, or, conversely, to express most fully the emotions of the performer, the illumination of the whole interior must be played upon. This is because of the very wide seeing angle of the eye—both horizontally and vertically—and because illumination, like the atmosphere, is all pervading, surrounding the whole person and the whole assemblage of persons. If the highest expression of this new art is to be conveyed a play on that all enveloping illumination must be secured.

This light play in the illumination of the interior should not be thought of as a mere grading up and down of intensity—with or without color changes. It is not confined to that, but may constitute an extension of the space to be illuminated. Starting, for instance, with a brilliantly lighted curtain and the auditorium in darkness, the glow may be made to grow in area, with the smoothness of a dawn, from a spot on the curtain to gradually reach the rear and covers the whole

*From a paper presented before a meeting of the Philadelphia Section of the Illuminating Engineering Society, Jan. 26, 1926, by Mary Hallock Greenewalt.

interior. In other words, a climax may be reached either by gradually increasing the intensity throughout or the area illuminated. And, of course, either of these processes may be reversed, or, to a certain extent, they may be combined.

This play on the whole interior illumination may be illustrated by phenomena of nature. Everyone is familiar with the change of mood which accompanies the passing of a heavy cloud across the face of the sun, or the gradual transformation of a brilliant morning into a cloudy day. Also, how ominous is an unusually heavy cloud, producing near-darkness at midday! Conversely, how may one's mood change when an overcast gloomy day clears at sunset and fills the world with glorious radiance and, be it observed, with glorious color. A day of doubt and skepticism closes with the conviction that "all's right with the world." Again, who has not been seated on terrace or lawn of a summer evening and become conscious of a soft radiance suffusing the landscape, slowly growing in clearness, until the full moon, having risen behind the foliage and at last surmounting the tree tops, spreads its glorious illumination through all space? The magic effect is not that of something viewed, but of being bathed in universal radiance. Depending on the arrangement of lamps, effects of similar type may be produced in any interior by one seated at the console of this light-color player. And color-play is not necessarily confined to screen or curtain on the stage, but may be suffused throughout the interior.

A play of light and color on a curtain or stage, watched by an audience seated in uniform darkness, or near-darkness, may be compared to a performance of music in the presence of a uniform buzzing or hissing sought throughout the auditorium. For its perfect enjoyment, music must be the only sound reaching the ear; it must be unconfused in the whole interior and dominate the consciousness of the listener. So it is with the play of light; it must be capable of filling the whole eye of the watcher and of dominating his emotions.

It probably goes without saying that this art of mobile light admits of projecting changing patterns or shapes (coloring them as desired) by providing mechanism for gradually changing the shapes of the beams thrown by the projecting lamps. The earliest experiments, many years ago, were concerned with this type of light and color-play, but it was soon realized that it is but one small phase of the main problem in developing this art of mobile light and color. However, it is an inclusive phase.

The console contains three rheostats, each about 30 30 in. high by 36 in. long, so designed and arranged that the illumination intensity given by the lamps connected to them can be changed by steps so small as to seem continuous. Mercury switches absolutely noiseless of operation are used, so arranged that the same body of mercury makes contact between a choice of various pairs of conducting leads. The console is relatively light in weight and is about 30 in. wide by 42 in. long. The seated player controls the play of light and color by using keys and pedals.

The auditorium accessory consists of an arrangement of switches in a separate compact box not over 20 in. long, connected to the console and to the wiring of the auditorium lighting system in such a manner that the illumination in large auditoriums, even those consuming a wattage as high as 250,000, may be varied up or down at will by minute steps, so as to seem continuous. The regular lighting system of an auditorium may be so connected and utilized, but, of course, if special effects are desired, or color effects, special lamps would need to be properly placed.

The lamp head is designed for getting different colors from exactly the same point and to save wattage. The lamp is mounted in a special reflector, and fitted with a color wheel equipped with variable timing control, and a color signalling attachment. For color-play on curtain or stage, the lamps would naturally be placed as the character of the distribution is helped. Separate lamps, each with its fixed color screen, may be used in place of the color wheel. Of course, for certain limited or temporary purposes, where it is desired to use the instrument for color-play as a stereopticon, the lamp head, or several of them, may be mounted directly on the console, thus providing a self-contained portable color-player.

A musical composition to secure permanence and permit of indefinite performance by others needs a written record. So with a light composition. A system of scoring has been designed for light compositions which anyone familiar with musical scores can easily master, and a basis of permanence for this new art is thus laid.

The development of an instrument to play with light and color, to be operated by one person, must have awaited the advent of the incandescent electric lamp; it could not have been done with the light from the candle, kerosene lamp or gas lamp. It has been helped by the development of high wattage, high candle power lamps, and of various technical devices, such as the mercury switch. It must have awaited facts developed by physiological research, including the seeing increments of the eye under varying intensities. A new means of emotional expression and of esthetic enjoyment is thus given to the world—who can predict the extent of its ultimate development? Perhaps a time will come when it will be a factor in heightening the enjoyment of music, deepening the devotion of religious worship, augmenting the effect of oratory, enhancing the brilliancy of dances, banquets and social functions, beautifying and refining whatever may be done on the stage, platform, or motion picture screen, and, when played on the silver curtain, becoming in itself a source of joy to the following generations.

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Annual Convention at White Sulphur June 21-25

A wide variety of technical subjects, the choice of a charming location, and enjoyable recreational features mark the program for the Annual Convention of the A. I. E. E. which will be held at The Greenbrier, White Sulphur Springs, W. Va., June 21-25, 1926.

Technical Sessions

The technical papers cover a broad range of subjects and the reports of the Technical Committees will describe the important developments which have occurred in the various fields of electrical theory and application. The papers will include the subjects of the theory of synchronous machines, non-harmonic alternating currents, a-c. circuits, dielectric breakdown, rectifiers, magnetization, heat transfer in machines, auto-transformers, electrical measurement of mechanical vibrations, remotely controlled substations, high-speed circuit breakers, regenerative braking and windings for d-c. machines. The accompanying tentative program gives more detailed information on the technical features.

The Attractive Location

No finer place than the Greenbrier at White Sulphur Springs could have been selected for the convention. This magnificent, modern hotel is located in the Greenbrier Mountains 2000 feet above sea level in most attractive surroundings. Small cottages, close to the main hotel, are available for those who desire them. There is every opportunity for outdoor sports and recreation. Close to the hotel there are two 18-hole golf courses which are among the finest in the country and also a splendid nine-hole course. Excellent tennis courts will be available and both golf and tennis tournaments are planned.

A swimming pool, 40 by 103 ft. in size and fed from one of the large springs, is another attraction at this hotel.

A fine stable of thoroughbred horses is maintained there and those interested may enjoy horseback riding on well kept trails over the mountain ridges through very beautiful scenery. Also automobile driving is very enjoyable in this country and many people motor to the Greenbrier from New York, Philadelphia and Washington.

Special Addresses

An interesting feature of the meeting will be the addresses on three organizations which play an important part in the electrical industry, namely, the International Electrotechnical Commission, the American Engineering Council and the American Engineering Standards Committee. The speakers will be C. H. Sharp, President of the U. S. National Committee of the I. E. C., L. W. Wallace, Executive Secretary, A. E. C., and C. E. Skinner, Chairman A. E. S. C. Many members will be glad to hear these talks on the objects, organization and activities of these bodies.

Recreation

The recreational side of the convention is receiving special attention and every afternoon will be free for sports and pleasure. There will be a reception and dance on Tuesday evening of the convention week and dancing will be enjoyed on other evenings.

The ladies will be especially welcome and many plans are being made for their enjoyment.

Section Delegates' Conference

During the morning and afternoon of Monday, June 21, a conference of the delegates of Institute Sections will be held under the suspices of the Sections Committee, but all interested are welcome to attend.

Registration and Hotel Accommodations

It will be appreciated if those who plan to attend the convention will notify Institute headquarters, 33 W. 39th Street, New York, as soon as possible.

Hotel accommodations should be reserved by communicating directly with The Greenbrier, White Sulphur Springs, W. Va. A list of rates is given below.

Rates per Person at The Greenbrier

Cost of Meals is Included

Single room without bath	$9.00
Single cottage room with use of bath (average five rooms per cottage with two or three baths)	$10.00
Double room (twin beds) and single room with bath between	$10.00
Two double rooms (twin beds) with bath between	$10.00
Two single rooms with bath between	$11.00
Double room (twin beds) with bath	$11.00
Single room with private bath	$12.00

Reduced Railroad Rates

Special railroad rates have been granted for those who attend the convention. These rates are available under the "certificate plan" which requires that each member or guest request a certificate when purchasing his railroad ticket to White Sulphur Springs. If 250 certificates are deposited with the Transportation Committee at The Greenbrier, each certificate holder is entitled to half-fare on his return trip over the same route. There are certain restrictions as to some limited trains, date of travel, etc., on which information should be obtained from local ticket agents.

Every member and guest should get a certificate whether or not he will use it. This will insure that those who want to take advantage of the reduced fare will not be deprived of the opportunity.

The following table shows the schedules on trains arriving in the morning in White Sulphur Springs from several cities. While this schedule will probably be in effect until after the convention, members should consult their local ticket agents relative to trains. It is advised that parlor-car and sleeping-car accommodations be reserved at the earliest possible date.

The general committee in charge of arrangements for the convention is as follows: Farley Osgood, Chairman, W. R. Collier, W. S. Lee, E. B. Meyer, W. E. Mitchell, A. M. Schoen and H. B. Smith.

SCHEDULE OF TRAINS ARRIVING AT WHITE SULPHUR SPRINGS IN THE MORNING

From the East

Lv. New York, Penn. Sta.	Penn. R. R.	5:45 p. m. (E.S.T.)
Lv. West Philadelphia	Penn. R. R.	7:53 p. m. (E.S.T.)
Lv. Wilmington	Penn. R. R.	8:34 p. m. (E.S.T.)
Lv. Baltimore	Penn. R. R.	10:00 p. m. (E.S.T.)
Lv. Pittsburgh	B. & O. Ry.	12:55 p. m. (E.S.T.)
Lv. Washington	C. & O. Ry.	11:20 p. m. (E.S.T.)
Ar. White Sulphur Springs	C. & O. Ry.	7:25 a. m. (E.S.T.)

This train carries through Pullman sleepers from New York.

From the West

Lv. Chicago	Big Four Ry.	1:00 p. m. (C.S.T.)
Lv. Indianapolis	Big Four Ry.	6:15 p. m. (C.S.T.)
Lv. St Louis	Big Four Ry.	12:00 Noon (C.S.T.)
Lv. Detroit	Mich. Cent. Ry.	12:20 Noon (E.S.T.)
Lv. Toledo	Big Four Ry.	2:00 .p m. (E.S.T.)
Lv. Louisville	C. & O. Ry.	6:00 p. m. (C.S.T.)
Lv. Cincinnati	C. & O. Ry.	9:10 p. m. (C.S.T.)
Ar. White Sulphur Springs	C. & O. Ry.	8:40 a. m. (E.S.T.)

This train carries through Pullman sleepers from Chicago, St. Louis, Cincinnati and Louisville to White Sulphur Springs.

E.S.T = Eastern Standard time C.S.T = Central Standard time.

TENTATIVE TECHNICAL PROGRAM

Tuesday Morning, June 22

President's Address, Dr. M. I. Pupin

Presentation of A. I. E. E. Prizes for Papers

Developments in Electrical Engineering as described in the reports of the Technical Committees and of the Standards Committee as indicated below.

Research, J. B. Whitehead, Chairman.
Electrophysics, J. H. Morecroft, Chairman.
Education, Harold Pender, Chairman.
Standards, H. S. Osborn, Chairman.
Instruments and Measurements, A. E. Knowlton, Chairman.
Communication, H. P. Charlesworth, Chairman.
Production and Application of Light, P. S. Millar, Chairman.
Electrical Machinery, H. M. Hobart, Chairman.

Wednesday Morning, June 23

Session A

Synchronous Machines (Extension and Interpretation of Blondel's Treatment), R. E. Doherty and C. A. Nickle, both of General Electric Co.

Non-Harmonic Alternating Currents, Frederick Bedell, Cornell University.

Graphical Solution of A-C. Circuits, F. W. Lee, Johns Hopkins University.

Session B

Remote Controlled Substations, W. C. Blackwood, N. Y. & Queens Elec. Lt. & Pr. Co.

The High-Speed Circuit Breaker in Railway Feeder Networks, J. W. McNairy, General Electric Co.

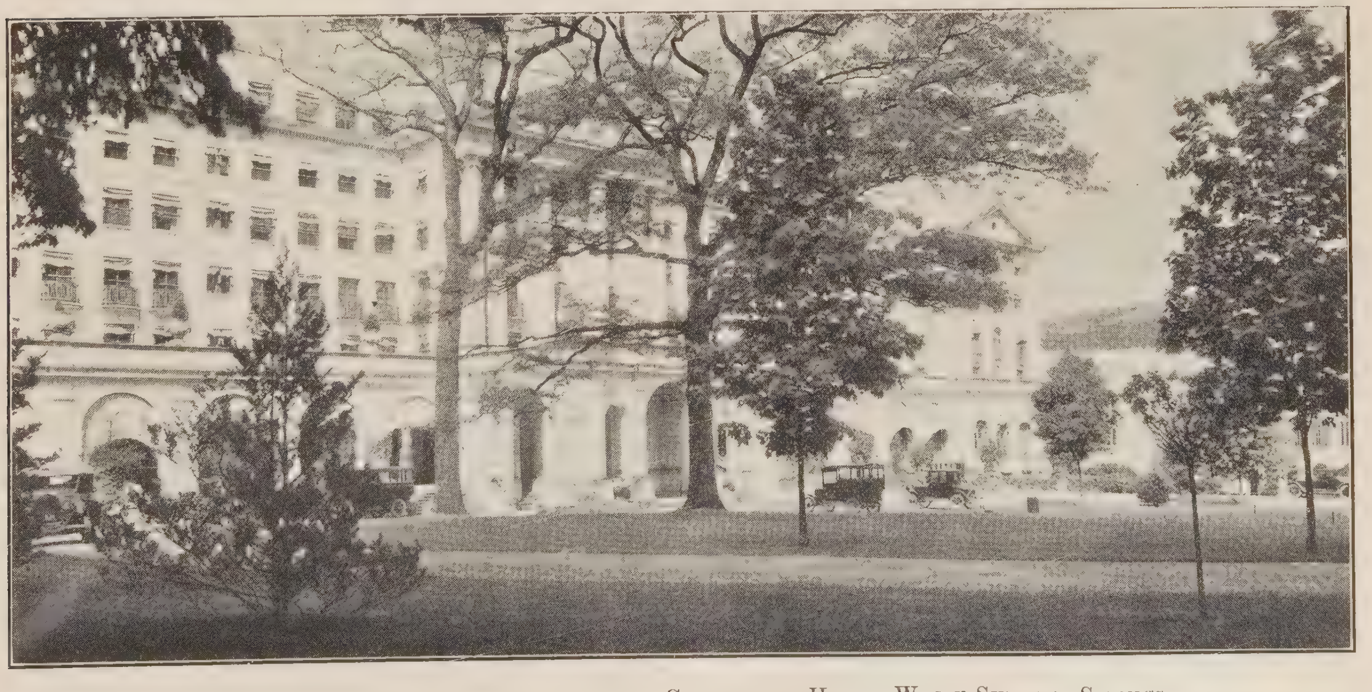
Regenerative Braking for D-C. Locomotives, Alfred Bredenberg, Jr., General Electric Co.

Multiplex Windings for D-C. Machines, C. C. Nelson, Massachusetts Inst. of Technology.

Thursday Morning, June 24

Developments in Electrical Engineering as described in the reports of the Technical Committees indicated below.

Power Generation, V. E. Alden, Chairman.
Power Transmission and Distribution, P. H. Thomas, Chairman.
Protective Devices, E. C. Stone, Chairman.
General Power Applications, A. M. MacCutcheon, Chairman.
Applications to Iron and Steel Production, F. B. Crosby, Chairman.
Applications to Mining Work, F. L. Stone, Chairman.
Applications to Marine Work, L. C. Brooks, Chairman.
Transportation, C. T. Hutchinson, Chairman.
Electrochemistry and Electrometallurgy, G. W. Vinal, Chairman.



A. I. E. E. Convention Headquarters—Greenbrier Hotel, White Sulphur Springs

FRIDAY MORNING, JUNE 25

SESSION A

The Mechanism of Breakdown of Dielectrics, P. L. Hoover, Harvard University.

Mercury-Arc Rectifiers, D. C. Prince, General Electric Co.

Electrical Recording of Vibrations, A. V. Mershon, General Electric Co.

SESSION B

Law of Magnetization, S. L. Gokhale, General Electric Co.

Surface Heat Transfer in Electric Machines with Forced Air Flow, O. E. Luke, Westinghouse Elec. & Mfg. Co.

General Theory of the Auto-Transformer, W. L. Upson, Washington University.

The Niagara Falls Regional Meeting

As we go to press with this issue of the JOURNAL, the Regional Meeting of the A. I. E. E. at Niagara Falls, N. Y., is convening for its first session. The number of early arrivals registered indicates an unusually good attendance, and the diversified program and excellent weather conditions which prevail presage a most interesting and enjoyable time for both the indoor and outdoor features of the meeting. The program was published in full in the May JOURNAL and preliminary copies have been mailed to all the membership in the eastern part of the United States. A complete account of this meeting will appear in the July JOURNAL.

Regional Meeting Held at Madison

The first regional meeting of the Great Lakes District of the Institute was held in Madison, Wis., May 6 and 7, with headquarters in the Hotel Loraine. It was most enjoyable and instructive to the one hundred eighty who attended. There were three well attended technical sessions, a regional dinner, and a number of interesting trips.

At the first session on Thursday, May 6, two papers were presented, namely, *Rural Electrification*, by G. C. Neff, and *Important Features of a Successful Plan for Rural Electrification*, by G. G. Post. Quite a number discussed these papers. Included were E. A. Stuart, A. H. Ford, E. H. Lehman, K. A. Pauly, Eugene Holcomb, C. B. Hayden and F. W. Duffee.

Three papers on high-voltage cable were presented Friday morning. These were as follows: *The Quality Rating of High-Tension Cable with Impregnated Paper Insulation*, by D. W. Roper and Herman Halperin; *Tests of Paper-Insulated, High-Tension Cable*, by F. M. Farmer; and *The Effect of Internal Vacua in High-Voltage Cables*, by W. A. Del Mar. These papers were received with great interest and extended discussion followed. Those taking part were: R. W. Atkinson, W. S. Clark, E. S. Lee, D. M. Simons, R. J. Wiseman, H. G. Burd, S. J. Rosch, Percy Dunsheath, E. C. Willman, F. A. Brownell, and E. M. Tingley.

Following these papers F. G. Boyce presented a paper on *Some Interconnected-System Operating Problems*. This was discussed by D. W. Roper, H. J. Burton, Carl Lee, and R. L. Dodd.

A session on *Cooperation between the Colleges and the Industries in Research* occupied Friday afternoon. Papers on this topic were read by the following: W. E. Wickenden (read by J. T. Rood), A. A. Potter (read by C. F. Harding), B. F. Bailey whose paper was entitled *Can the University Aid Industry?*, and Edward Bennett whose paper was entitled *Seminars for Practising Engineers*. Those contributing discussions were E. B. Paine, John Mills, S. H. Mortensen, J. S. Coldwell, F. E. Tourneur, and C. F. Harding.

L. J. Peters then presented a paper on *Behavior of Radio Receiving Systems to Signal and to Interference* which was discussed by Prof. Edward Bennett.

An enjoyable feature of the meeting was the regional dinner held on Thursday evening. A very inspiring address was made by Dr. Glenn Frank, President of the University of Wisconsin. Dr. Frank drew attention to the present sociological and economic problems of this country and suggested as possible remedies two courses of action. The first he called a "new scientific renaissance" which could be accomplished by making the knowledge of researchers in all lines of science available for general understanding and practical utilization. The second remedy he called a "new industrial revolution." The main lines of action in such a revolution would be four, namely, (1) to decentralize industry, (2) to regularize production and distribution, eliminating excessive seasonal activities, (3) to reduce unemployment, and (4) to allay the insecurity of the labor class. In elaborating on these propositions Dr. Frank suggested as one means of accomplishing them, the small factory making standardized parts and situated in farm territory where laborers might alternate between farm work and factory work.

Meetings of the Branch Counselors of the District were held on Thursday and Friday at which were present the counselors of ten Branches and several other professors who were interested.

Many of the visitors took the trips which were arranged in and around Madison and a number also found time to play golf.

Student Convention Held at M. I. T.

A convention of enrolled students of the Northeastern District of the A. I. E. E. was held at Massachusetts Institute of Technology, Cambridge, Mass., on May 7. The meeting, which was arranged by a student committee assisted by the Boston Section, had an attendance of one hundred sixty. There were three technical papers presented and a number of inspection trips were made. A banquet was also given.

At the technical session in the morning, at which S. A. Tucker, Chairman of the Yale Branch, presided, the following papers were presented: *D-C. Transmission Considerations*, by S. W. Marshall, M. I. T. graduate; *A Phase of Distribution Engineering*, by O. W. Briden, Brown 1926; and *Electrical Characteristics of Richmond Station of the Philadelphia Electric Company*, by Constantine Barry, M. I. T. 1927.

At the banquet in the evening, Prof. H. B. Smith, Vice-President in the Northeastern District, was toastmaster. Dr. S. W. Stratton, President of Massachusetts Institute of Technology, welcomed those present in a short talk, after which three addresses were made. Dr. M. I. Pupin, President of the A. I. E. E., chose as his subject *Science and Engineering*. He was followed by Prof. C. F. Scott, Yale University, who spoke on *How Student Branches Came into Being*, and R. E. Doherty, Consulting Engineer, General Electric Company, who spoke on *Employment with a Large Manufacturing Company*.

In the afternoon many took the trips which were made to the following places: Edgar Station of the Edison Electric Illuminating Company; the plant of the Simplex Wire and Cable Company; a machine-switching exchange of the New England Telephone Company; and the M. I. T. Laboratories.

A meeting and luncheon of the Branch Counselors of the District was held at which every Counselor was present besides a number of others interested in Branch and Section activities.

Establishing of Louisville Section

A meeting was held on May 13 in Louisville, Kentucky to consider the advantages of establishing a local Section of the Institute in that city. Some sixteen A. I. E. E. members were present and listened to an interesting talk on the value of local Sections given by W. E. Mitchell of the Alabama Power Company, Vice-President of the A. I. E. E. from the Southern District. It was decided that the establishing of a local Section in Louisville would be a distinct advantage to every one concerned and a committee was appointed to complete the formalities and present a report at a meeting to be held in September. Those named on the committee were, E. D. Wood, Operating Electrical Engineer, Louisville Gas & Electric Co. and D. C. Jackson, Jr., Professor of Mechanical and Electrical Engineering at the University of Louisville.

Cummings C. Chesney

PRESIDENT-ELECT OF THE A. I. E. E.

Cummings C. Chesney, Manager and Chief Engineer, General Electric Company, Pittsfield, Mass., has been elected President of the American Institute of Electrical Engineers for the year beginning August 1, 1926, as announced in the report of the Committee of Tellers published elsewhere in this issue.

President-elect Chesney was born in Selingsgrove, Pa., October 28, 1863. He was graduated from Pennsylvania State College in 1885, and for three years taught mathematics and chemistry. In 1888 he joined Mr. William Stanley's laboratory force at Great Barrington, Mass., and the following year entered the services of the United States Electric Lighting Company in Newark, N. J., a subsidiary of the Westinghouse Electric and Manufacturing Company. In 1890 he moved to Pittsfield, Mass., where he was one of the original incorporations of the Stanley Electric Manufacturing Company, started with a capital of $25,000. The company was organized to develop the alternating-current inventions of William Stanley, John Kelley and C. C. Chesney. The work was primarily of a pioneer character with little precedent to guide it.

C. C. Chesney

This company developed the well-known S. K. C. system (Stanley, Kelly, Chesney). The first polyphase transmission plant equipped with the S. K. C. system to be put into successful operation and the first in America was installed in 1893 and is supplying power and light today for use in the towns of Housatonic and Great Barrington, Massachusetts. In 1895 a 12,000-volt plant was installed for service from Lowell to Grand Rapids, Michigan. The operating success of these alternators was due to special design in which the high-tension currents were generated in the stator element by the revolving rotor, these being the first alternators to produce a true sine wave. As early as 1896 alternating-current generators of 6000 volts with control equipment were put into successful operation on the transmission line of the Montmorency Electric Power Company, Quebec. In 1898 generators up to 12,000 volts were placed in service. During the early period two-phase alternating-current induction motors were developed, electrostatic condensers at 500 volts and electric transformers of 100-light capacity. In developing the transformer all spaces in the coils were filled with Gilsenite to provide better heat dissipation and insulation. This occurred as early as 1892, as did the development of cloth treated with oxidized linseed oil. The most effective general insulation in use today was developed by the Stanley Company, in 1891-1892, superseding the old insulating methods using shellac and P. & B. paint. In 1893 belt-driven alternators were put into successful operation and in 1899 alternators of this design direct-connected to steam engines went into successful operation in the power house of the Staten Island Electric Company. These were the first alternators to be operated in parallel and in regular commercial service. Switchboard instruments, high-tension arc breaking devices, frequency indicators, indicating wattmeters, lightning protection for high and low-tension currents, condensers, etc., were among other apparatus manufactured by the Stanley Company. The company built the first revolving field types of alternators used in America. These were extensively used in hydraulic stations, notably the Bay Counties and Standard companies' lines in California, at that time the longest high-voltage lines in the world, using 40,000 to 60,000 volts.

Mr. Chesney was vice-president and chief engineer of the Stanley Company from 1904 to 1906. On the latter date he took up the duties of chief engineer and manager of the Pittsfield works of the General Electric Company, which company had acquired the Stanley Manufacturing Company. Under Mr. Chesney's supervision the Pittsfield works in recent years have made particular progress in the development of apparatus for commercial service up to 220,000 volts, and lately have completed successful tests of 1,000,000 volts for transmission purposes.

Mr. Chesney is a Fellow of the Institute, and has taken an active interest in its affairs. He served as manager from 1905 to 1908 and as vice-president from 1908 to 1910. He is also a member of the Society of Arts, London, of the American Society for the Advancement of Science and of the Engineers Club of New York. During the year 1920 he was president of the Engineering Society of Western Massachusetts. He has always had a strong civic interest, taking an active part in the life of his community. He is chairman of the industrial committee of the crippled

children's home in Pittsfield, one of the best equipped industrial rehabilitation schools for children in New England; and is director of the Agricultural Bank and president of the Morris Plan Bank of Pittsfield.

The Edison Medal was awarded to Mr. Chesney in 1921, "for early developments in alternating-current transmission."

A. I. E. E. Directors' Meeting

The regular meeting of the Board of Directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on Friday, May 21, 1926.

There were present: President M. I. Pupin, New York; Vice-Presidents Harold B. Smith, Worcester, Mass.; Arthur G. Pierce, Cleveland, Ohio; Managers H. M. Hobart, Schenectady, N. Y.; G. L. Knight, Brooklyn, N. Y.; National Secretary F. L. Hutchinson, New York.

A minute was adopted in memory of the late Carl Hering, Past President of the Institute.

Reports were presented of meetings of the Board of Examiners held April 26 and May 17, 1926, and the actions taken at those meetings were approved. Upon the recommendation of the Board of Examiners, the following actions were taken upon pending applications: 93 Students were ordered enrolled; 164 applicants were elected to the grade of Associate; 18 applicants were elected to the grade of Member; 1 applicant was elected to the grade of Fellow; 3 applicants were transferred to the grade of Fellow; 18 applicants were transferred to the grade of Member.

The Board ratified the approval by the Finance Committee, for payment, of monthly bills amounting to $21,343.99.

The National Secretary reported 1330 members delinquent in the payment of dues for the fiscal year ending April 30, 1926; and the Board directed that the usual efforts be continued to collect these dues, through the Secretary's office and by bringing the list to the attention of the Section officers concerned.

The annual report of the Board of Directors for the fiscal year ending April 30, 1926, as prepared in the National Secretary's office was presented and accepted for presentation at the annual business meeting of the Institute to be held during the evening of the same day. The annual report of the National Treasurer was presented, accepted, and ordered filed.

The annual reports of various standing committees (exclusive of the technical committees, whose reports will be presented at the Annual Convention in June), abstracts of which were incorporated in the Board of Directors' report, were received and ordered filed for reference by the committees of the next administration.

The following new by-law was adopted, in order to incorporate in the Institute by-laws the action taken by the Board of Directors on April 9, 1926, in adopting the policy of providing for the affiliation with the Institute of engineering student organizations in colleges in which it is not feasible to establish Student Branches of the Institute because of the limited number of students:

"Sec. 59A. An established student engineering society in a university or technical school of recognized standing may, upon application of its officers and a member of the Institute connected with the school, and the approval of the Board of Directors, become associated with the Institute. Members of such associated student engineering society may have the same privileges as enrolled Students of the Institute and will be governed by the same requirements."

Upon the recommendation of the Committee on Student Branches, the Board approved for printing and distribution in pamphlet form, "Suggested By-laws for Student Branches."

The Standards Committee submitted for the Board's approval, a revision of Section 7 of the A. I. E. E. Standards (Alternators, Synchronous Motors and Synchronous Machines in General), and the Board voted to approve the recommended revision.

An invitation to nominate a candidate for the 1926 Kelvin Medal was accepted and referred to the President with power. President Pupin stated that he would confer with the presidents of the other Founder Societies before acting in the matter.

In accordance with Section 37 of the constitution, the Board considered the appointment of a National Secretary for the administrative year beginning August 1, 1926, and National Secretary F. L. Hutchinson was reappointed.

Other matters of importance were discussed, reference to which may be found in this and future issues of the Journal.

Board of Directors' Report for the Year Ending April 30, 1926

The annual report of the Board of Directors of the American Institute of Electrical Engineers was presented at the annual business meeting of the Institute held in New York Friday evening, May 21.

This report consists of a brief summary of the principal activities of the Institute during the year, including abstracts of various reports submitted by officers and committees, covering their respective branches of work. The more important matters referred to in the report have been, or will be, covered in much more detailed form in the Journal, and therefore the report will not be published in full herein; but any member of the Institute may obtain a pamphlet copy upon application to the National Secretary.

The growth in Institute membership during the year is indicated in the following tabulation:

	Honorary	Fellow	Member	Associate	Total
Membership on April 30, 1925......	4	597	2,436	14,282	17,319
Additions:					
Transferred........		33	178		
New Members Qualified..............		5	97	1,976	
Reinstated.........			8	45	
Total.............	4	635	2,719	16.303	
Deductions:					
Died..............		7	16	71	
Resigned..........		2	36	333	
Transferred........			18	193	
Dropped...........		1	26	800	
Membership, April 30, 1926......	4	625	2,623	14,906	18,158
Net increase in Membership during the year....................					839

The activity of the Sections and Branches during the year and the growth in the number of these organizations, also in the number of meetings held by them and in the aggregate attendance, are shown in the following statement:

	For Fiscal Year Ending			
	May 1 1919	May 1 1921	May 1 1923	May 1 1926
SECTION				
Number of Sections......	34	42	46	51
Number of Section meetings held..............	217	303	344	405
Total Attendance........	25,837	37,823	46,672	58,959
BRANCHES				
Number of Branches.....	61	65	68	86
Number of Branch meetings held............	156	443	503	714
Attendance............	6,441	21,629	26,893	35,270

The Finance Committee's report, together with the general balance sheet and detailed financial statements of the public accountants who audited the Institute's books, is included in the report.

Report of Committee of Tellers on Election of Officers

To the President,

American Institute of Electrical Engineers

DEAR SIR:

This committee has carefully canvassed the ballots cast for officers for the year 1926-1927. The result is as follows:

Total number of ballot envelopes received		4811
Rejected on account of bearing no identifying name on outer envelope, according to Art. VI, Sec. 34 of the Constitution	43	
Rejected on account of voter being in arrears for dues for year ending May 1, 1926, as provided in the Constitution and By-Laws	99	
Rejected on account of ballot not being enclosed in inner envelope, or being improperly marked, or on account of inner envelope or ballot bearing an identifying name, according to Art. VI, Sec. 34, of the Constitution	111	
Rejected on account of having reached the Secretary's office after May 1, according to Art. VI, Sec. 34, of the Constitution	14	267
Leaving as valid ballots		4544

These valid ballots were counted, and the result is shown as follows:

FOR PRESIDENT	
C. C. Chesney	4399
Blank	145
FOR VICE-PRESIDENTS	
District	
No. 1 *North Eastern*	
H. M. Hobart	4397
Blank	147
No. 3 *New York*	
G. L. Knight	4385
Blank	159
No. 5 *Great Lakes*	
B. G. Jamieson	4402
Blank	142
No. 7 *South West*	
A. E. Bettis	4362
Blank	182
No. 9 *North West*	
H. H. Schoolfield	4371
Blank	173
FOR MANAGERS	
F. J. Chesterman	4441
Blank	103
H. C. Don Carlos	4433
Blank	111
I. E. Moultrop	4439
Blank	105
FOR TREASURER	
George A. Hamilton	4407
Blank	137

Respectfully submitted,

SERGIUS P. GRACE, *Chairman*
E. S. HOLCOMBE
W. E. COOVER
E. F. THRALL
E. F. WATSON
J. T. WELLS
Committee of Tellers.

Date May 10, 1926.

Annual Meeting of A. S. T. M.

The Twenty-Ninth Annual Meeting of the American Society for Testing Materials will be held at Chalfonte-Haddon Hall, Atlantic City, N. J., June 21-25 inclusive. The program will be diversified including the following sessions: Tuesday morning Committee Meetings; afternoon, First Session, Wrought Iron, Cast Iron and Magnetic Testing. Wednesday, June 23, (a. m.) Third Session, Steel; Fourth Session, Brick, Tile, Refractories and Fire Tests; Fifth Session, (p. m.), Edgar Marburg Lecture. Thursday, June 24, (a. m.), Sixth Session, Corrosion and Fatigue of Metals; Seventh Session, Road Materials, Waterproofing, Petroleum Products and Thermometers. Evening Sessions, Non-Ferrous Metals and Metallography; Textiles, Rubber, Coal, Timber, Insulating Materials and Slate. Tenth Session, Symposium on Resin. Friday, June 25th, (a. m.), Eleventh Session, Preservative Coatings and Naval Stores; Twelfth Session, Cement, Lime, Gypsum and Nomenclature.

Special, reduced rates have been prearranged for those who wish to attend if 250 certificates are filed, and as he registers, each member will receive a complete set of reports and papers prepared for this meeting. Golf and tennis tournaments, an informal dance and smoker will supply entertainment of a more recreative nature.

1926 Convention of the Illuminating Engineering Society

The Twentieth Annual Convention of the Illuminating Engineering Society will be held at Spring Lake, N. J., from September 7-10, inclusive, with headquarters at the Essex and Sussex Hotel. The Essex and Sussex is ideally located directly on the ocean front, a short trip from New York and Philadelphia. It is beautifully appointed and enjoys a most enviable reputation for its service and cuisine.

A well-rounded papers program is being prepared with special features showing the developments in specific fields which have taken place during the twenty years of existence of the Society. Special and unique features are also being planned for the entertainment program and it is confidently expected that the 1926 Convention will prove to be a most successful one.

Annual Meeting and New York Section Meeting, May 21, 1926

The annual business meeting of the Institute was held at the Engineering Societies Building, New York, on Friday evening, May 21, 1926. President Pupin presided, and called upon National Secretary Hutchinson, who presented in abstract the annual report of the Board of Directors, printed copies of which had been distributed to members in attendance. (This report is referred to elsewhere in this issue).

The report of the Committee of Tellers on the election of officers of the Institute was then presented by Mr. Hutchinson, and, in accordance therewith, President Pupin declared the election of the following officers, whose terms will begin on August 1, 1926:

PRESIDENT:	Cummings C. Chesney, Pittsfield, Mass.
VICE-PRESIDENTS:	
District No. 1	H. M. Hobart, Schenectady, N. Y.
District No. 3	George L. Knight, Brooklyn, N. Y.
District No. 5	B. G. Jamieson, Chicago, Ill.
District No. 7	A. E. Bettis, Kansas City, Mo.
District No. 9	H. H. Schoolfield, Portland, Ore.
MANAGERS:	F. J. Chesterman, Pittsburgh, Pa.
	H. C. Don Carlos, Toronto, Ont.
	I. E. Moultrop, Boston, Mass.
NATIONAL TREASURER:	George A. Hamilton, Elizabeth, N. J.

These officers, together with the following hold-over officers, will constitute the Board of Directors for the next administrative year, beginning August 1: M. I. Pupin, New York; Farley Osgood, New York; P. M. Downing, San Francisco, Calif.; Herbert S. Sands, Denver, Colo.; W. E. Mitchell, Birmingham, Ala.; Arthur G. Pierce, Cleveland, Ohio; W. P. Dobson, Toronto, Ont.; W. M. McConahey, Sharon, Pa.; W. K. Vanderpoel, New York; H. P. Charlesworth, New York; John B. Whitehead, Baltimore, Md.; J. M. Bryant, Austin, Tex.; E. B. Merriam,

Schenectady, N. Y.; M. M. Fowler, Chicago, Ill.; H. A. Kidder, New York; E. C. Stone, Pittsburgh, Pa.

Dr. Pupin then called upon Mr. H. A. Kidder to preside during the remainder of the meeting which was under the auspices of the New York Section.

Chairman Kidder, after a few preliminary remarks on the value of modern methods of obtaining data on circuit breaker performance as compared with the early days when the certainty of performance of a breaker was an almost unknown quantity, introduced the speaker of the evening, W. R. Woodward, General Engineer, Westinghouse Elec. & Mfg. Co., Pittsburgh, Pa. In the presentation of his paper, "A High-Power Laboratory for Testing Oil Circuit Breakers and Other Apparatus," Mr. Woodward outlined the advantages and disadvantages of factory testing as compared to field tests, described the ever increasing demand for larger and larger test sets, and the effort which has been made to make the laboratory complete, flexible, and safe. The paper was profusely illustrated with lantern slides. Discussion of the paper was given by R. M. Spurck, G. E. Co., and E. K. Read of the Westinghouse Co.

The Montefiore Triennial Prize

April 30, 1927 has been set as the latest date upon which papers may be submitted to the jury of award for the George Montefiore Foundation Medal.

This prize is awarded every three years upon the basis of international competition for the best original work in scientific progress and progress in technical application of electricity in any of its branches. Popular works and simple compilations are precluded. Papers submitted are subject to the following general stipulations:

Only such papers as have been prepared during the three years preceding the meeting of the acting jury will be acceptable; all must be either printed or typewritten, in both French and English, and twelve copies sent free of postage to M. le secretaire-archiviste de la Foundation George Montefiore, rue Saint-Gilles, 31 Liege, Belgium, by whom they will be acknowledged to the author. A majority vote of four-fifths by the board of award allows of one-third of the amount available being bestowed for the presentation of a valuable discovery in the scientific field or the statement of a new idea which may lead to important development in electrical progression. Should the prize for any year not be awarded or any portion of it remain undistributed this amount will be added to the award for the next triennial period. Any paper upon which the jury decides will be published in the Bulletin de l'Association des Ingenieurs électriciens of l'Institut électro-technique Montefiore, 25 reprints to be sent to the author free of charge but no further profit to be derived by him from its reprinting. The award carries with it a gratuity of 20,500 francs (about $600) to be distributed at the discrimination of the jury of award, which is comprised of ten electrical engineers, all holding diplomas of the Institute Electrotechnique Montefiore, five Belgians and five others, presided over by the director of the Institute Electro-Technique Montefiore, who automatically becomes one of the Belgian delegates.

At the head of all papers submitted, or in some other conspicuous place should be plainly written: "Travail soumis au concours de la Foundation George Montefiore, session de 1923-1926" (Paper submitted for the competition of the George Montefiore Foundation).

American Engineering Standards Committee

WELCOME SUGGESTIONS ON SYMBOLS AND ABBREVIATIONS

Under the auspices of the American Engineering Standards Committee, an undertaking which will lead eventually to the standardization of scientific and engineering symbols and abbreviations has now been fairly launched. The sectional committee, which in its representation includes thirty-one trade, technical and scientific bodies, held its organization meeting January 21, 1926, societies taking the leading part in the work as sponsors being, the American Association for the Advancement of Science, the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Society of Mechanical Engineers and the Society for the Promotion of Engineering Education. The secretary of the sectional committee, (Preston S. Millar, Electrical Testing Laboratories, 80th Street and East End Avenue, New York City) will be very glad to receive in cooperation any suggestions which interested organizations may care to make with regard to symbols and abbreviations to be adopted in the various fields of engineering and industry. Completion of the entire work will require the participation of many interests; it is the committee's present plan to concentrate upon the fields in which there is the greatest need of unification of standards, taking up further work as opportunity affords.

Carnegie Institute Summer Course

Excepting a few guest instructors and special lecturers, none but members of the regular college teaching staff has been appointed to the faculty for the summer courses this year at the Carnegie Institute of Technology, according to an announcement from the Pittsburgh institution. The guest members of the faculty, it is further announced, will be on duty at various periods during the six weeks' courses for teachers from June 28 to August 6 in the College of Fine Arts. For the eight weeks' courses from June 4 to August 6 for undergraduates in the industrial and engineering courses, only members of the regular college faculty have been engaged.

As a result of the increasing interest shown in the type of technical instruction featured at this institution. Carnegie officials report plans to receive another large enrolment of summer students for this year.

ENGINEERING FOUNDATION

EDWARD DEAN ADAMS GIVES GENEROUSLY TO RESEARCH

A gift of $100,000 has been made to the Engineering Foundation and the Engineering Societies Library by Edward Dean Adams, as announced by W. L. Saunders President of the United Engineering Society and Chairman of its endowment committee at a meeting of the Foundation the evening of May 19th when a dinner was held at the Union League, with Mr. Adams as guest of honor.

This generous gift of Mr. Adams' brings research endowment fund up to a total of $650,000, with Mr. Ambrose Swasey's initial endowment of $500,000 and the $50,000 received under the will of the late Henry R. Towne.

The sum of $12,000 was contributed toward the support and promulgation of a fundamental research in blast furnace slags, now in progress at the University of Wisconsin under the direction of Richard S. McCaffery, member of the Institute of Mining Engineers and Professor of Metallurgy at the University. The investigation is being conducted with the understanding that information established by the work done will be contributed to the research data of the Engineering Foundation before the 20th of each January, covering progress of the preceding calendar year; any unused portion of the funds appropriated to revert to the Foundation.

The Foundation also voted $5000 a year for two years, to promote electrical insulation research on the specific subject of dielectric absorption, through investigation to be conducted at the Johns Hopkins University under the direction of John B. Whitehead, Fellow of the American Institute of Electrical Engineers and Professor of Electrical Engineering at Johns

Hopkins University. Results on these investigations are to be returned to the Foundation before January 20th of each year covering the previous calendar year with full accounting of the funds expended and return of any residue which may exist.

The personnel of the Endowment Committee is as follows:

Ex officiis:

W. L. Saunders, President, United Engineering Society, *Chairman.*

L. B. Stillwell, Chairman, Engineering Foundation.

Sydney H. Ball, Chairman, Library Board.

Nominees of American Society of Civil Engineers:

Charles F. Loweth, Chicago; Chief Engineer, Chicago, Milwaukee & St. Paul Railway.

H. deB. Parsons, New York; Consulting Engineer.

Ralph J. Reed, Los Angeles; Chief Engr., Union Oil Company.

Nominees of American Inst. of Mining and Metallurgical Engineers:

D. W. Brunton, Denver; Chairman, Board of Consulting Engineers, Moffatt Tunnel.

J. V. N. Dorr, President, The Dorr Company (metallurgical, chemical and sanitary process equipment). New York.

Thomas Robins, New York; President, Robins Conveying Belt Co., member, Naval Consulting Board.

Nominees of American Society of Mechanical Engineers:

J. W. Lieb, New York; Vice-President & General Manager, The New York Edison Company.

Wynne Meredith, San Francisco; member of firm, Sanderson & Porter.

E. A. Simmons, New York; President, Simmons-Boardman Publishing Company.

Nominees of American Institute of Electrical Engineers:

Calvert Townley, New York; Assistant to President, Westinghouse Electric & Manufacturing Company.

H. A. Lardner, Vice-President, J. G. White Engineering Corporation, New York.

E. Wilbur Rice, Jr., Schenectady; Honorary Chairman, General Electric Company.

Members-at-large:

Charles F. Rand, New York; Past-President, American Inst. of Mining and Metallurgical Engineers.

James H. Perkins, New York; President, The Farmers' Loan and Trust Company, financial adviser and custodian of securities for United Engineering Society.

H. Hobart Porter, New York, of Sanderson & Porter, and President, American Water Works & Electric Company.

Robinson Fellowship—Ohio State University

At a recent meeting of the Robinson Fellowship Committee it was voted to recommend Mr. Herbert L. Rawlins of Fredericktown, Ohio, Senior in Electrical Engineering, for the award of the Stillman W. Robinson Fellowship for the year 1926-27.

This fellowship has a value of $750 and provides that the successful applicant shall devote his entire time to graduate study and research, leading to the degree of Master of Electrical Engineering.

This fellowship was endowed by Stillman W. Robinson, formerly Professor of Mechanical Engineering and a famous inventor of shoe and other automatic machinery. Professor Robinson also gave the University the large experimental boiler in the Mechanical Engineering Department.

Dr. E. J. Berg Gives Steinmetz Lecture Before Schenectady Section

The second Steinmetz Lecture, entitled *The Solution of Transient Phenomena by Elementary Mathematics* was delivered by Dr. Ernst J. Berg, Professor of Electrical Engineering, Union University, at the meeting of the Schenectady Section on April 23. The Steinmetz Lectures are a series of annual addresses which was instituted last year by the Schenectady Section in honor of the late Dr. C. P. Steinmetz. The first address was given by Dr. M. I. Pupin in 1925. For the second lecture Dr. Berg selected a subject in which Dr. Steinmetz was deeply interested throughout his lifetime. The lecture was much appreciated by the 450 who were present. Copies of the address may be obtained from Institute headquarters, New York.

National Capital Park and Planning Commission

Since the development of plans for this Commission, engineers generally have been interested because of a proposal to make prominent engineers from the District of Columbia and elsewhere, members. Under the provision of the Act at least one man would be appointed from the District of Columbia and as announced on May 19th at the White House engineers are pleased to find a prominent member of their profession, F. A. Delano, on the list of appointees. Other men prominent in the engineering architectural development of city planning appointed to the and Commission by the President, were:

M. B. Medary, Philadelphia, Pa., President of the American Institute of Architects,

F. L. Ohmstead, of Boston, Mass.,

J. C. Nichols, of Kansas City, Mo.

Bureau of Standards Visiting Committee Meets

The Visiting Committee of the Bureau of Standards met with Director Burgess at the Bureau on April 29th. This body is composed of five scientists appointed by the Secretary of Commerce and entrusted with the work of going over the policy of the Bureau from time to time to look into the status of scientific experimentations and outline new phases of investigation.

It is understood that the Committee, during its recent meeting, went over the requirements of the Bureau of Standards and worked with the Director in developing some plans for the future. The nature of the Committee's report has not been disclosed. It was stated by Dr. George K. Burgess, Director of the Bureau, that the complete report will be submitted at a later date. The members of the Committee are: Wilder D. Bancroft, of Cornell University; Gano Dunn, New York; William F. Durand, New York; Samuel W. Stratton, Massachusetts Institute of Technology, and Ambrose Swasey, of Cleveland, Ohio. Prior to their meeting at the Bureau, the committee paid a complimentary call on Secretary Hoover.

Three members of the committee are also members of the American Institute of Electrical Engineers.

Stamp Memorial to John Ericsson

Postmaster General New has authorized a special five cent postage as a memorial to John Ericsson, engineer, builder of the *Monitor*, according to an announcement at the Post Office Department under date of May 5th. It is understood that an issue of 15,000,000 of these stamps will be placed on sale first at New York City, Chicago, Minneapolis and Washington, on May 29th. The stamp is being released simultaneously with the unveiling of the John Ericsson Memorial Statue in Potomac Park, Washington, D. C., on May 29th.

According to a statement issued by the State Department the Crown Prince of Sweden will unveil the statue. Representatives of the leading engineering and allied technical organizations of America have been invited to attend this ceremony. The subject of the stamp will be a replica of the John Ericsson Memorial, designed by the sculptor, James Earle Fraser.

Levy Medal to F. W. Peek, Jr.

Frank W. Peek, Jr., consulting engineer of the General Electric Company in charge of the company's high voltage experimental laboratory at Pittsfield, Mass., was awarded the Levy gold medal by the Franklin Institute of Philadelphia. This award, founded by Louis Edward Levy, was given Mr. Peek in recognition of his paper presented a year ago before the institute on "High-Voltage Phenomena."

Mr. Peek is one of the world's best known figures today in the investigation of artificial lightning and high voltages. He has produced, in the General Electric's laboratory, voltages greater than two million. Outstanding in his research work has been his formation and establishment of laws regarding corona, the investigation of lightning and its effect on high voltage transmission, the study of dielectric phenomena, line insulations and the problems connected with the transmission of high voltage currents.

Obituary

Carl Hering, pioneer electrical engineer and an outstanding figure in today's electrical engineering circles, died suddenly on Monday, May 10th, at the Hahnemann Hospital, Philadelphia, where he had gone to recuperate from what he considered a slight affection of the heart.

Born in Philadelphia in 1860, Doctor Hering's early education was through the schools of that city and in Germany. He quickly became a leader in the technical world, especially in the electrical field in its modern form, which had just sprung into being as he arrived at the age of manhood. In 1880, he graduated from the University of Pennsylvania with a degree of Bachelor of Science and high honors; seven years later, he had conferred upon him the post-graduate degree of M. E. and again, in later years, he received from this same university the honorary degree of Doctor of Science. In 1882, while teaching at the university, he began the study of electrical engineering and in 1883 he published his first technical article, the precursor of a long series of contributions to the profession, including innumerable papers read before the various societies, press articles and no less than eight books. In this same year he was appointed a member of the jury for the international electrical exhibition in Vienna and in the years following he was called upon at least eleven times for similar service both in Europe and at home. There was scarcely an international or otherwise important exhibition associated with the electrical art in which he did not participate. In 1885 he became chief electrical engineer for a German company manufacturing and installing motors and dynamos, but early in 1886 he returned to his native country to practise consulting electrical engineering in the city of Philadelphia. In 1889 he was appointed officer of Public Instruction by the French Government, which, in 1891, made him Knight of the Legion of Honor. Among his many other attainments, Doctor Hering was an enthusiast on the subject of scientific explanation of exceptions to generally accepted physical laws, and through his own personal research, contributed much to the classification of electrical nomenclature. In 1892 he was technical editor of the *Electrical World* and a year later established the "Digest of Current Electrical Literature." For ten years he conducted a department, abstracting notable articles on electrical science in all technical papers of the world. Doctor Hering's work in the electrochemical world began prior to 1890 with extended researches into storage batteries. From these results he obtained numerous patents. He also investigated the regeneration of battery solutions and, in 1900 made electric furnace tests for the reduction of arsenic ore. Some six years later, while designing and operating electric furnaces, he began a series of experiments which resulted in the discovery of a new electromagnetic force to contract a conductor through which current is flowing even to the extent of rupture, when it is fluid. This was known as the "pinch" effect. He also discovered other effects showing that the electromagnetic forces act upon the material of the conductor. In 1909 he applied these forces to impart rapid motion to molten masses and based upon this principle, he invented an electric furnace now in wide commercial use. As early in his career as 1883 he was computing conversion factors for electrical and mechanical energy, publishing a comprehensive treatise on this subject in 1904. A few years later, however, he recalculated all electrochemical equivalents. In 1908 he made exhaustive analyses of the interrelations of various units entering into the calculation of light phenomena and in that same year he described an experiment purporting to demonstrate a hitherto unrecognized factor in electromagnetic induction to show that the well-known Maxwell law of induction should be modified in order to become universal. Doctor Hering was one of the three men to plan and organize the American Electrochemical Society and was also instrumental in founding the *Electrochemical Industry* now *Chemical and Metallurgical Engineering*, published by the McGraw-Hill Publishing Company.

In 1900-1901 he served the Institute as its President; in 1904 he was elected president of the Engineers' Club and in 1906, president of the American Electrochemical Society. Other scientific groups of which he was a valued member are American Association for the Advancement of Science, the Franklin Institute and Illuminating Engineering Society.

At its May 21 meeting, the Board of Directors of the A. I. E. E. passed the following Resolution:

In the death of Dr. Carl Hering on May 10th a distinguished member has been removed from the ranks of the A. I. E. E. pioneers. From eighteen eighty-eight, when he affiliated with the Institute, down through his years of faithful and able service as a committeeman and as President in 1900 and 1901, Dr. Hering stood firmly for the maintenance of Institute ideals. It is with a sense of the great loss sustained that the Board of Directors hereby extends to his family and associates its sincere sympathy, and orders this minute spread upon the records.

Robert Sanford Riley died Friday, May 7, 1926. His death closes a career of much more than usual success not only in his home community but also throughout the entire engineering world. Coupled with high ability, he had high humanity. He led but also served.

Mr. Riley was born in Canada in 1874. His boyhood was spent in Winnipeg. Both his father and mother are descended from a line of old Yorkshire, England. He was graduated with honors in 1896 from Worcester Polytechnic Institute.

He began his business career as an apprentice in a locomotive works. Between 1898 and 1903 Mr. Riley worked his way around the world as a marine engineer starting from Cramp's shipyard in a ship which as draftsman he had helped to design. Sailing the Pacific in the Empress Line, he joined the United States Navy in Hong Kong. He went through the boxer uprising and came home via the Indian Ocean and Suez Canal as chief engineer of the *Arethusa*, a naval auxiliary used as a base ship for torpedo boats. He left the sea to enter the employ of the New York Ship Building Company.

In 1906 Mr. Riley became manager of the American Ship Windlass Co. of Providence, R. I., and here he had an opportunity to put his naval engineering experience to further use in the design of windlasses and steering engines. He soon specialized on the "Taylor" stoker, then being manufactured by the American Ship Windlass Co. in the crude form in which it was left by the death of the inventor. Mr. Riley redesigned and improved the "Taylor" stoker and built up a large business, and became known as a pioneer in the commercial development of high capacity under-feed stokers.

In 1911 Mr. Riley sold out his interests in the American Ship Windlass Co. and later organized the Danford Riley Stoker

Company of Worcester, Mass., to develop and market the Riley Self-Dumping Underfeed stoker.

In July 1918, Mr. Riley's services were called for by the Emergency Fleet Corporation under Chas. L. Schwab. He organized a department for the conducting of trial trips and observing performance in service of boats of the Emergency Fleet Corporation which in January 1919 he turned over to the permanent organization of the Emergency Fleet Corporation.

In 1918 Mr. Riley was elected President of the Worcester Chamber of Commerce and was re-elected in 1919. He was vice-president of the Worcester Y. M. C. A., a member of the A. S. M. E. and served on various of its committees, contributing many valuable papers, he was a member of the Naval Architects and Marine Engineers, the Alpine Club of America, the Appalachian Club, Engineers Clubs of Boston and New York, the Worcester Club, the Tatnuck Country Club, the Detroit Athletic Club. He took an active interest in the movement for the betterment of the city, and was a large contributor to its worthy causes. He gave not only of his money but of his time and energies.

Henry Fleetwood Albright, Fellow of the Institute and since 1917 vice-president of the Western Electric Company, Chicago, died Tuesday, May 11th, after an illness of several months.

Mr. Albright was born in Lancaster, Pennsylvania, October 5th, 1868. Immediately upon his graduation from the Philadelphia High School, he started his technical education under private tutelage and in 1886 entered the employ of the Fuel Gas and Electric Company of Pittsburgh which, at that time, was installing all Westinghouse plants. In 1892 he joined the Western Electric Company as a salesman of electric light and power apparatus in Chicago, and two years later was transferred to its Construction Department in New York, in 1897 becoming plant engineer of the New York factory. His brilliant success and natural aptitude led, in 1899, to his advancement to the position of general manager, and eight years later he received his appointment as general superintendent of the company's manufacturing plants. Shortly thereafter, he again removed to Chicago, where he was largely responsible for the building of the Hawthorne Works of the Western Electric Company, starting its development on a prairie site on the outskirts of Chicago in 1904 and developing it into the largest telephone factory in the world. Almost forty thousand men and women were employed and Mr. Albright's outstanding contribution to it was scientific factory planning and management. At the time of his death he was head of all the company's manufacturing and plant engineering activities.

Closely coupled with his managerial and scientific ability was his aptitude for making friends, and to this qualification, allied with his natural application and zest to any undertaking, may be attributed Mr. Albright's achieved brilliant success.

Mr. Albright joined the Institute in 1892 in the grade of Associate, but advanced to full Member March 20, 1894 and became a Fellow in 1912, typifying in this, as in all of his activities, his constant progression.

William H. Forde, Associate of the Institute and Electrical Engineer for the Stone & Webster Company, Boston, was killed in an automobile accident at Conowingo, Maryland, May 11th.

Mr. Forde was born in Natick, Mass., February 14, 1893. In 1913 he graduated from the Electrical Engineering course at Sheffield Scientific School, and his first position was light and power solicitor for the El Paso Electric Railway Co. He then became solicitor of light and power for the Electric Company, Milford, Mass., and later spent two years as salesman for the Electric Storage Battery Company, Boston. In July 1912, Mr. Forde was chosen electrical inspector for the Stone & Webster Company, with whom he was still affiliated at the time of his death.

PERSONAL MENTION

W. R. Marshall, formerly branch manager for the Westinghouse Company at Buffalo has been selected for new duties as District Manager, Pittsburgh, Pa.

Henry Eggelhof, Dallas, Texas, was recently appointed exclusive representative for the Eastern half of Texas by the Uehling Instrument Co. of Paterson, N. J.

Erwin G. Fleming has been transferred from the Central Station Engineering Dept. of the General Electric Company, Schenectady to the Jacksonville, Fla. office. Mr. Fleming will stay at Miami.

C. W. Stokes has joined the organization of the American Brown Boveri Electric Corporation and will be connected with their Chicago office. He was formerly Canadian manager for the English Electric Co., Ltd., and also for a number of years manager for the Sterling Engineering Co., Montreal, Canada.

L. C. Brooks, who has been identified with the Electrical Marine Industry since the first electric ships (The U. S. S. *Kearsage* and *Kentucky* built at Newport News in 1900) and whose resignation as Electrical Engineer of the Bethlehem Shipbuilding Corporation was recently announced, may now be addressed at Groton, Mass. He is taking a much needed rest before forming other business connections, but in the meantime will continue his interests along marine lines. Mr. Brooks has served as chairman of the Institute Committee on Application to Marine Work.

Addresses Wanted

A list of names of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th St., New York, N. Y.

All members are urged to notify the Institute Headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—William E. Ames, Detroit Edison Co., Detroit, Mich.
2.—H. R. Bailey, Electric Bldg., Portland, Ore.
3.—J. Roy Barclay, 3424 Harrison St., Kansas City, Mo.
4.—Hubert L. Clary, 782 West 24th St., Milwaukee, Wis.
5.—J. F. Clinton, 3682 Broadway, New York, N. Y.
6.—J. E. Contesti, 350 W. 58th St., New York, N. Y.
7.—Hugh Denehy, The Inst. of Elect. Engrs., Savoy Pl., Victoria Embankment, London W. C. 2. Eng.
8.—Ralph Elsman, 120 Broadway, New York, N. Y.
9.—Charles A. Foust, 10505 93rd St., Woodhaven, N. Y.
10.—George Frasher, 1209 So., 4th Ave., Louisville, Ky.
11.—S. Alden Griffin, 19 Elliott St., Springfield, Mass.
12.—Harold G. Haines, 7416 Sylvester, Detroit, Mich.
13.—William A. Hincy, Colonial Apts., Media, Pa.
14.—Elmer D. Johnson, 1481 Harvard St., Washington, D. C.
15.—John E. Lewis, 376 Meyran Ave., Pittsburgh, Pa.
16.—F. A. Lindlof, 610 So. Spring St., Los Angeles, Calif.
17.—Charles W. Lueek, 1454 First Ave., New York, N. Y.
18.—Charles W. Magee, c/o Pelser, 210 West 102nd St., New York, N. Y.
19.—Shu-Sing Man, 541 West 124th St., New York, N. Y.
20.—J. A. McDermott, Y. M. C. A., Lima, Ohio.
21.—Irving Menschik, c/o Dublier Cond. & Radio Corp., 48 W. 4th St., New York, N. Y.

22.—Erwin H. Mitchell, c/o Schmeltz, 481 6th St., Brooklyn, N. Y.
23.—Robert H. Russell, 1128 Warren West, Detroit, Mich.
24.—Lieut. A. G. Scott, 68 West 107th St., New York, N. Y.
25.—Kermit G. Seaman, P. O. Box No. 68, Boulder, Colo.
26.—A. B. Smedley, c/o Cooper Hewitt Elec. Co., 1406 First Nat'l. Bank Bldg., Cincinnati, Ohio.
27.—C. D. Smith, 857 St. Charles St., New Orleans, La.
28.—Will M. Strickler, 301 Detroit Life Bldg., Detroit, Mich.
29.—O. G. Utt, 4738 Oak St., Kansas City, Mo.
30.—Leo A. Van Etsen, 1100 Park Ave., New York, N. Y.
31.—John D. Walker, 2686 Woodstock Ave., Swissvale, Pa.
32.—A. R. Williamson, 561 Delaware Ave., Norwood, Pa.
33.—C. A. Winder, Southern Equipment Co., San Antonio, Texas.

Book Review

NEW HANDBOOKS OF THE BUREAU OF STANDARDS

Handbooks No. 6 and No. 7, giving Safety Rules for the Installation and Maintenance of Electrical Supply Stations and Electric Utilization Equipment, respectively, are now on distribution through the Bureau of Standards, Washington. Price 10 cents each. These are published in small 5-in. by 7-in. paper covered pamphlets No. 6 comprising Part I the Grounding Rules of the fourth edition of the National Electrical Safety Code, while No. 7 consists of Part III and the Grounding Rules of the fourth edition of the National Electrical Safety Code. Publication dates, February 5 and March 12, 1926, respectively. Address Superintendent of Documents, Government Printing Office, Washington, D. C.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES (MAY 1-30, 1926)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

CRYSTALLINE FORM AND CHEMICAL CONSTITUTION.

By A. E. H. Tutton. Lond. & N. Y., Macmillan & Co., 926. 252 pp., illus., diagrs., tables, 9 x 6 in., cloth. $3.60.

An account of the present position of chemical crystallography, based upon a course of lectures delivered at Cambridge University. The book is intended primarily for students of chemistry, physics or mineralogy, but an introductory chapter which summarizes the essential facts of pure crystallography renders it available to readers unfamiliar with the subject.

AUSGEWAHLTE METHODEN FUR SCHIEDSANALYSEN UND KONTRADIKTRISCHES ARBEITEN BEI DER UNTERSUCHUNG VON ERZEN, METALLEN UND SONSTIGEN HUTTENPRODUKTEN....

By Gesellschaft Deutscher Metallhutten-und Bergleute. Berlin, The Society, 1926. (Mitteilungen, t. 2). 146 pp., 9 x 6 in., boards. $2.50.

A collection of methods for the chemical analysis of metals and ores, recommended by the Chemical Section of the Society of German Metallurgists and Miners for umpire analyses. The methods cover the examination of zinc, zinc ash and zinc ores; cadmium; nickel, nickel ores and alloys; cobalt and bismuth, and their ores and alloys; lead compounds; magnesium and its alloys; corundum and carborundum; and the secondary ingredients in antimony and its ores. A chapter on proper methods of sampling is included.

APPAREILLAGE ELECTRIQUE.

By P. Maurer. Paris, Gauthier-Villars et Cie., 1926. 317 pp., illus., diagrs., tables, 10 x 6 in., paper. 55 fr.

A text-book on apparatus for interrupting, protecting, regulating and distributing electricity. The treatment is largely descriptive and treats of the design and use of switches, circuit-breakers, rheostats and switch-boards of the commercial types in use in France.

DICTIONARY OF APPLIED CHEMISTRY, v. 6.

By Sir Edward Thorpe. Revised & enlarged edition. Lond. & N. Y., Longmans, Green & Co., 1926. 791 pp., illus., diagrs., 9 x 6 in., cloth. $20.00.

The death of Sir Edward Thorpe, in February, 1925, interrupted the completion of the Dictionary, but publication is now resumed under the editorship of Dr. H. Forster Morley, and it is hoped to complete the work during 1926.

The present volume includes a number of lengthy articles on substances of great industrial importance, prepared by competent authorities. Saponification, silver, soap, sodium and its salts, starch, sugar, sulfur, sulfuric acid, synthetic drugs, tannins and tantalum are thus treated, together with many others. The new edition easily maintains the work in its rank as the leading English encyclopedia of industrial chemistry.

FUNDAMENTAL CONCEPTS OF PHYSICS IN THE LIGHT OF MODERN DISCOVERY.

By Paul R. Heyl. Balt., Md., Williams & Wilkins Co., 1926. 112 pp., 7 x 5 in., cloth. $2.00.

An account of the evolution of our present concepts through the eighteenth, nineteenth and twentieth centuries. Dr. Heyl studies the antecedents of present views, tracing correlations, analogies and similarities wherever they are found, and regarding the concepts in their philosophical aspects. The book is an interesting, non-mathematical description, accompanied by a list of references to more detailed works.

GUTERUMSCHLAG.

Die Guterumschlag-Verkehrswoche des V. D. I. in Düsseldorf und Köln, 1925. Sonderausgabe der Zeitschrift des V. D. I. Berlin, V. D. I. Verlag, 1926. 256 pp., illus., diagrs., 11 x 8 in., paper. 30.-rm.

In September, 1925, a week-long conference on the problems of freight traffic was held in Düsseldorf and Cologne under the auspices of the Verein Deutsche Ingenieure. The papers presented appeared in the V. D. I. Zeitschrift and are now collected in the present volume.

While questions of railroad freight handling are most extensively treated, there are papers on boat traffic, harbor machinery, street and light railroads, motor-truck and airship freight handling. Special attention is given to loading and unloading machinery and to the efficient utilization of equipment.

HERTHA AYRTON; a Memoir.

By Evelyn Sharp. London., Edward Arnold & Co., 1926. 304 pp., illus., port., 9 x 6 in., cloth. $5.50. (Gift of Longmans, Green & Co., N. Y.)

Mrs. Ayrton's chief interest to engineers arises from her investigations of the electric arc, which were published in book form in 1902. In 1899 she was elected a member of the Institution of Electrical Engineers, being the first woman to attain that distinction. She also engaged in an investigation of the formation of sand ripples, which led her, during the War, to the invention of the Ayrton fan, a device for driving back poison gas.

Her biographer traces her career from early childhood to her death in 1923.

INTRODUCTION TO INDUSTRIAL CHEMISTRY

By S. I. Levy. N. Y., McGraw-Hill Book Co., 1926. 288 pp., illus., diagrs., 8 x 6 in., cloth. $4.00.

Dr. Levy's book departs from the usual textbook on industrial chemistry, which deals with the specialized technique of particular branches of chemical industry. Instead, he offers a general introduction to the whole subject, in which are discussed such matters as costing, methods of heating, cooling, pulverizing, filtering, extracting, distilling, drying, etc., on a large scale, and the transporting and handling of gases and liquids. The presentation of these foundation processes is supplemented by brief accounts of certain selected industries; fuel, sulfuric acid, alkali, intermediates and explosives. The book is intended to bridge the gap between the methods of the laboratory and those used industrially.

LOKOMOTIVVERSUCHE IN RUSSLAND.

By G. Lomonossoff. Berlin, V. D. I. Verlag, 1926. 330 pp., illus., diagrs., tables, 12 x 9 in., cloth. 42.-mk.

In the years 1898 to 1900, Professor Lomonossoff devised a method for testing locomotives, by which the engine was subjected to the working conditions customary for laboratory tests, on the actual roadway instead of in the laboratory. Wind resistance and the jolting from passage over the rails here introduce factors absent from laboratory tests.

Since 1908 the method has been used in Russia to investigate each new type of locomotive. The present work presents some of the results of tests made from 1908 to 1923.

The purpose and method of testing is first explained. The eight types of locomotives tested are then fully described, after which the results of tests on a locomotive of the newest Russian type are given in detail. The most important results of the tests of the remaining types of locomotives are then given. The final chapter illustrates the use of the experimental results for the solution of problems of locomotive operation.

METHODS OF MEASURING TEMPERATURE.

By Ezer Griffiths. 2nd edition. Lond., Charles Griffin & Co.; Phila., J. B. Lippincott Co., 1926. 203 pp., illus., tables, 9 x 6 in., cloth. 10s 6d.

Written for those concerned with the measurement of temperature in scientific investigations or in industrial operations. Attention is given chiefly to the experimental basis of the methods in general use, the calibration of the instruments and the precautions to be observed in practice.

A connected account of the classical researches with the gas thermometer is given. Subsequent chapters deal with the mercury thermometer, the resistance thermometer, the thermocouple, the radiation pyrometer and the optical pyrometer. References are appended to each chapter.

The changes in this edition are, in addition to the correction of errata, chiefly in the portion on optical pyrometry.

POWER-FACTOR WASTES.

By Charles R. Underhill. N. Y., McGraw-Hill Book Co., 1926. 326 pp., illus., diagrs., tables, 9 x 6 in., cloth. $3.50.

This discussion of power-factor wastes is intended to present the subject from many points of view and thus to direct more attention to their importance. It aims to acquaint those responsible for these wastes with their causes, their cost and their cures. Many chapters are contributed by specialists on their subjects.

PYROMETERS.

By Ezer Griffiths. Lond. & N. Y., Isaac Pitman & Sons, 1926. 126 pp., illus., diagrs., tables, 7 x 5 in., cloth. $2.25.

Intended as a connecting link between textbooks on heat and advanced treatises on pyrometry, this little book describes recent pyrometric apparatus, including expansion thermometers, thermoelectric pyrometers, resistance thermometers, optical and total radiation pyrometers. Only a few types of each class are described, but these have been selected from outfits designed to meet unusual requirements.

RAILROAD ELECTRIFICATION AND THE ELECTRIC LOCOMOTIVE.

By Arthur J. Manson. 2nd edition. N. Y., Simmons-Boardman Publishing Co., 1925. 332 pp., illus., diagrs., tables, 9 x 6 in., cloth. $4.00.

Intended to provide information of value to those concerned with the operation and maintenance of electric locomotives, or interested in the general subject of railroad electrification. Technical detail is reduced to small dimensions, but the fundamental units and principles of electricity are explained, the design and construction of electric locomotives are described and illustrated, and the solutions of a number of practical problems incident to electrification are given. An appendix gives a brief history of electrification in the United States.

TOPOGRAPHICAL DRAWING NOTES.

By G. P. Schubert. 2nd edition. Houghton, Mich., Michigan College of Mines, 1926. 82 pp., 11 drawings & diagrs., 6 x 9 in., cloth. $1.65.

This textbook supplements the lectures and laboratory work in a course on topographical drawing and traverse computations given at the Michigan College of Mines. It treats various methods of calculating and plotting traverses and of drawing suitable topographic maps. The course is planned to enable surveyors and mining engineers to do as much of this class of work as they may be called upon to do in their regular practice.

Past Section and Branch Meetings

SECTION MEETINGS

Boston

Modern Methods of Combustion Control, by E. G. Bailey, Bailey Meter Co. Joint meeting with A. S. M. E. April 15. Attendance 150.

The Art of Making Good Concrete, by W. C. Voss, Portland Cement Association; E. S. Larned, Civil Engineer, and J. G. Ahlers, Barney-Ahlers Construction Corp. Joint meeting. April 21. Attendance 228.

Chicago

Automatic Stations and Their Remote Supervision, by Chester Lichtenberg, General Electric Co. Joint meeting with Western Society of Engineers. May 3. Attendance 200.

Cincinnati

Modernizing Industrial Control Apparatus, by G. O. Wilms, Allen-Bradley Company. April 8. Attendance 84.

Cleveland

Industrial Motor Bearings from a Maintenance Point of View, by H. G. Veit, National Malleable Castings Co.;

Large Synchronous Motors for Industrial Drives, by P. C. Jones, Goodyear Tire and Rubber Co., and

Some Design Features of Industrial Motors, by E. E. Dreese, Lincoln Electric Co. April 22. Attendance 93.

Connecticut

Relativity and the Einstein Theory, by W. B. Hall, Yale University. April 29. Attendance 65.

Denver

Operation of D-C. Motors on Direct and Alternating Current Simultaneously, by Edwin Heath, University of Colorado;

Some New Developments in High-Voltage Insulators, by P. M. Brown, University of Colorado; and

The Application of Vacuum Tubes to Magnetic-Flux Measurements, by K. A. Browne, University of Colorado. April 16. Attendance 70.

Engineering in Russia, by S. M. Marshall, Perine and Marshall. April 22. Attendance 28.

Detroit-Ann Arbor

Power from Mercury Vapor, by W. L. R. Emmet, General Electric Co. Illustrated by slides and motion picture. March 16. Attendance 200.

Inspection trip to River Rouge Plant of the Ford Motor Company. April 3. Attendance 50.

Power Factor, What Is It and What Can We Do About It, by E. L. Bailey, Sales Engineer. Joint meeting with Detroit Engineering Society. April 23. Attendance 175.

Erie

Oil-Electric Locomotives, by Herman Lemp, Consulting Engineer. Illustrated with slides. Joint meeting with A. S. M. E. and A. C. S. April 20. Attendance 200.

Fort Wayne

The Consolidation of the Traction Company with the Insull Properties, by R. M. Fuestel, Indiana Service Corporation. Illustrated with motion pictures. April 28. Attendance 54.

Indianapolis-Lafayette

The Development of Steam Generators and Radiant Heat, by G. A. Orrok. Joint meeting with A. S. M. E. April 20. Attendance 119.

Ithaca

Finding and Filling Your Place in Industry, by C. R. Dooley, Standard Oil Company of New Jersey. March 15. Attendance 200.

Lightning and High-Voltage Phenomena, by F. W. Peek, Jr., General Electric Co. April 14. Attendance 70.

The Social and Economical Aspect of Niagara Falls Power, by W. K. Bradbury. May 7. Attendance 130.

Kansas City

Light Radiations as Shown by the Spectroscope, by F. E. Johnson, Kansas University Engineering School;

Loop Feeders of the Kansas City Power and Light Company, by W. O. Edmonds, Kansas City Power and Light Co., and

Super Power Systems, by B. J. Denman, United Light and Power Co. March 31. Attendance 48.

Lightning Protective Devices, by A. L. Atherton, Westinghouse Electric and Mfg. Co. The following officers were elected: Chairman, R. L. Baldwin; Secretary, S. M. DeCamp. April 30. Attendance 51.

Los Angeles

Modern Developments in Astronomical Research, by Ferdinand Ellerman, Mount Wilson Observatory. Illustrated. May 4. Attendance 150.

Lynn

The Industrial Conditions of the Nation, by D. S. Kimball, Cornell University, and

The Activities of Lynn, by Hon. Ralph S. Bauer, Mayor. March 20. Attendance 184.

Mexico

Maximum-Demand Meters, by Solis Payan. May 6. Attendance 18.

Milwaukee

The Mechanical Engineer in the Large Industries Today, by O. A. Anderson, Armour and Company. March 17. Attendance 70.

The Tremendous Responsibilities Which Confront the Engineer, by Roy Wright, Vice-President, A. S. M. E. April 21. Attendance 60.

Minnesota

Transmission of Pictures over Wire, by R. D. Parker, American Telephone and Telegraph Co. April 26. Attendance 150.

Nebraska

Tasks Ahead in Engineering Education, by O. J. Ferguson, University of Nebraska. April 9. Attendance 35.

Niagara Frontier

Automatic Train Control, by W. H. Reichard, General Railway Signal Company. The following officers were elected: Chairman, H. B. Alverson; Secretary-Treasurer, A. W. Underhill, Jr. April 30. Attendance 42.

Philadelphia

Progress, by L. F. Deming, General Electric Co. Illustrated with slides. April 12. Attendance 105.

Pittsburgh

Lightning, by F. W. Peek, Jr. Illustrated with slides and motion picture. The election of the following officers was announced: Chairman, W. C. Goodwin; Secretary, D. M. Simons. May 11. Attendance 385.

Pittsfield

Annual Dinner, held at the Hotel Wendell. The speakers were: C. C. Chesney, President-Elect of the A. I. E. E.; H. M. Hobart, Vice-President-Elect in District No. 1; Harold B. Smith, Vice-President in District No. 1; E. D. Eby, Chairman of the Pittsfield Section, and Dr. J. J. Walsh of Brooklyn, N. Y. Entertainment was furnished by the Radio Four Quartet, the Kilowatt Orchestra—an orchestra composed of electrical engineers, and Harold B. May's dance orchestra. The program was broadcast through WGY. March 30. Attendance 309.

Inspection trip to the Schenectady Works of the General Electric Company. April 19. Attendance 350.

Portland

The Influence of Line Voltage upon Induction-Motor Characteristics, by C. H. Bjorquist and H. E. Rhoads;

The Effect of Three-Phase Transformer Connections on Induced Harmonics, by D. O. Bergey, E. E. Kearns and C. W. Leihy, and

The Characteristics of Distribution Transformers at High Overloads, by F. C. Mueler, C. R. McLean, B. E. Plowman, O. W. Hurd and W. W. Bonar. These papers were presented by senior students of the Oregon Agricultural College. A demonstration of first-aid methods was also given by members of the Pacific Telephone and Telegraph Co. April 9. Attendance 135.

Providence

Fundamental Considerations of Power Limits of Transmission Systems, by R. E. Doherty, General Electric Co. Joint meeting with A. S. M. E. and Providence Engineering Society. April 8. Attendance 35.

Most Recent Radio Developments, by E. L. Bowles, Massachusetts Institute of Technology. The following officers were elected: Chairman, E. E. Nelson; Vice-Chairman, F. N. Tompkins, and Secretary-Treasurer, F. W. Smith. April 20. Attendance 60.

San Francisco

Manufacture, Treatment and Testing of Special Alloy Steels, by G. A. Richardson. Joint meeting with A. S. M. E., A. S. C. E. and Chemical Society. April 14. Attendance 250.

Engineering Education—Its History and Prospects, by H. H. Henline, Stanford University. April 23. Attendance 80.

St. Louis

The Position of Capital in the Electrical Industry, by W. A. Layman, Wagner Electric Corp. September 16. Attendance 122.

Lightning, by E. E. F. Creighton, General Electric Co. October 23. Attendance 275.

The Klydonograph and Its Application, by J. H. Cox, Westinghouse Electric and Mfg. Co. November 18. Attendance 102.

Engineering Research, by B. L. Newkirk, General Electric Co. December 16. Attendance 200.

Long-Distance Cable Communication, by H. H. Nance, American Telephone and Telegraph Co. January 20. Attendance 162.

Dance. Joint with A. S. M. E. February 17. Attendance 205.

Development of Electric Power Generation and Distribution, by Col. Peter Junkersfeld, McClellan and Junkersfeld. March 17. Attendance 180.

Automatic Stations, by C. A. Butcher, Westinghouse Elec. & Mfg. Co. April 21. Attendance 60.

Schenectady

The Relation between Technical and Business Training, by J. G. Callan, Harvard College of Business Administration. April 16. Attendance 350.

Seattle

Cost Analysis of Engineering Problems, by E. G. Champreux, The Pacific Telephone and Telegraph Co. The following officers were elected: Chairman, C. E. Mong; Secretary-Treasurer, C. R. Wallace. April 21. Attendance 81.

Sharon

Steel-Mill Electrification, by G. E. Stoltz, Westinghouse Electric & Mfg. Co. May 4. Attendance 101.

Spokane

Automatic Train-Control Equipment, by R. C. Charlton, Oregon-Washington Railroad and Navigation Co. April 23. Attendance 40.

Saskatchewan

Annual Meeting. The following officers were elected: Chairman, S. R. Parker; Secretary-Treasurer, W. P. Brattle. April 15.

Springfield

Automatic and Supervisory Controlled Substation, by R. J. Wensley, Westinghouse Elec. & Mfg. Co. April 20. Attendance 100.

Toronto

High-Power Laboratory of the Westinghouse Electric and Manufacturing Company, by W. R. Woodward. April 23. Attendance 300.

Toronto—Past and Present, by T. A. Reed. The following officers were elected: Chairman, M. B. Hastings, Secretary, F. F. Ambuhl. May 7. Attendance 63.

Utah

Loud-Speaker Horns, by J. V. Laird;

Electro-Chemical Reduction of Metals, by S. M. Young;

A Proposed Railway Electrification, by C. E. Hoffman;

Characteristics of Vacuum Tubes, by I. S. Pierson; and

Automatic Control of Substations, by A. LaMont Nelson. These papers were furnished by students of the University of Utah. April 28. Attendance 22.

Vancouver

Some Recent Developments in Urban Transportation, by H. M. Lloyd, British Columbia Electric Railway Co., Ltd. April 6. Attendance 26.

Washington

Developments in Motor-Vehicle Headlighting, by Lieut-Col. R. E. Carlson, Bureau of Standards. The following officers were elected: Chairman, C. A. Robinson; Vice-Chairman, M. G. Lloyd; Secretary-Treasurer, D. S. Wegg. May 11. Attendance 38.

Worcester

Electrical Reproduction of Music, by H. H. Newell, Worcester Polytechnic Institute. May 5. Attendance 80.

BRANCH MEETINGS

Alabama Polytechnic Institute

Business Meeting. The following officers were elected: Chairman, J. D. Stewart; Vice-Chairman, W. L. Garlington; Secretary-Treasurer, I. L. Knox. April 21. Attendance 22.

The Application of the X-Ray to Industry, by Dr. Fred Allison. May 5. Attendance 52.

University of Arizona

Power-Distribution Practise, by B. L. Jones;

Mine Lighting, by S. A. Sinclair, and

Underground Power Installation, by W. T. Wishart. April 10. Attendance 18.

University of Arkansas

Engineering English, by Dr. Jones. November 3. Attendance 32.

Natural-Period Vibration of Machinery, by Prof. Theorle, and

Equipment of a Modern Power Plant, by E. Reynolds. November 17. Attendance 28.

Power Distribution, by A. S. O'Bar;

Benefits of Engineering Organization, by B. A. Avery, and

Production of Casing-Head Gas, by E. T. Martin. December 1. Attendance 28.

Carrier Waves in Telephony, by R. A. Austin, and

Economy in Modern Steam Locomotives, by F. H. Smith. January 19. Attendance 20.

Gas-Engine Electric Railways as Used in England, by Frank Lane, and

Engineering Exhibit at Arkansas State Fair, by J. F. Toohey. February 2. Attendance 25.

Improved Methods of Combustion, by Prof. Strate. April 7. Attendance 11.

Development and Use of Searchlights, by Russell McFarland, and

Automobile Lights, by Elmer Nichols. April 20. Attendance 14.

High-Frequency Apparatus, by E. F. Nichols. The following officers were elected: President, Carroll Walsh; Vice-President, C. W. Collier; Secretary-Treasurer, W. H. Mann. May 4. Attendance 15.

Armour Institute of Technology

Smoker. April 14. Attendance 71.

Business Meeting. The following officers were elected: Chairman, M. T. Goetz; Secretary, C. W. Schramm; Treasurer, C. W. Burcky. May 6.

Brooklyn Polytechnic Institute

Motion pictures, entitled respectively "Revelations by X-Ray," "Endurance Tests of Induction Motors," and "Manufacture of Okonite Cables," were shown. April 14. Attendance 45.

California Institute of Technology

Business Meeting. April 27. Attendance 23.

Inspection trip to the Shrine Temple in Los Angeles. April 30. Attendance 12.

University of California

Inspection trip to P. T. & T. Co. January 29. Attendance 30.

Inspection trip to G. & E. Co. Broadcasting Station KGO. February 9. Attendance 45.

Inspection trip to P. T. & T. Co. March 17. Attendance 25.

Business Meeting. April 14. Attendance 31.

Case School of Applied Science

The Application of Carbon Products to Industry, by P. D. Manbeck, National Carbon Co., Inc. April 27. Attendance 38.

Catholic University of America

Radio, by B. J. Kroeger. Illustrated with slides. April 22. Attendance 21.

University of Colorado

Operation of a Series Motor with A-C. and D-C. Simultaneously, by Edwin Heath;

High-Voltage Insulators, by P. M. Brown. Illustrated with slides.

The Measurement of Magnetic Flux by the Use of the Vacuum Tube, by Kenneth Brown. April 16. Attendance 50.

University of Florida

Construction and Operation of Gas-Electric Busses, by F. P. Dean, and

Early Development of Steam Engine, by G. C. Robertson. April 26. Attendance 15.

Georgia School of Technology

Business Meeting. The following officers were elected: President, W. M. McGraw; Secretary-Treasurer, F. L. Kaestle. April 20. Attendance 45.

State University of Iowa

The Selenium Cell and Its Uses, by A. J. Plath. and

The Cathode-Ray Oscillograph, by R. B. Prunty. April 14. Attendance 34.

Wind Power, by Theo. Van Law;

Atomic-Hydrogen Arc Welding, by R. C. Van Ness, and

Insulating Materials Used in Transformers, by R. H. Perry. April 21. Attendance 33.

A motion picture, entitled "Coal is King," was shown. April 28. Attendance 35.

Patent Laws, by G. Gunderson, and

110-Volt Filamentless Vacuum Tube, by N. Jensen. May 5. Attendance 36.

Kansas State College

The Theory of Electrostatic and Electromagnetic Fields, by E. R. Lyons. January 12. Attendance 83.

Synchronous Machinery and Equipment, by E. S. Henningsen, General Electric Co. March 4. Attendance 98.

Growth of Utilities, by Arthur Groesbeck, United Light and Power Corp. April 12. Attendance 72.

Public-Utility Publicity, by H. W. Davis. April 27. Attendance 55.

Lafayette College

Talks were given by C. L. Craven and P. O. Farnham. March 31. Attendance 21.

Inspection trip to Lehigh Telephone Company's Central Station in Easton, Pa. April 7. Attendance 20.

The Use of Compressed Air in Industry, by A. H. Taylor, Ingersoll-Rand Co. April 28. Attendance 21.

Lehigh University

Some Problems of the Electrical Industry, by L. W. W. Morrow, Managing Editor, *Electrical World*, and

Organization and Operation of a Public Utility, by Chas. Zug, Jr., student. March 11. Attendance 49.

Recent Developments in Electric Traction, by J. D. Alrich, General Electric Co. A motion picture, entitled "Electrification of the Mexican Railroad," was shown. April 15. Attendance 66.

Lewis Institute

The Use of Mercury-Arc Rectifiers in Substations, by R. B. Freston. April 30. Attendance 18.

Massachusetts Institute of Technology

The Outlook for the Electrical Engineer Now in College, by Dr. E. W. Wickenden, Society for the Promotion of Engineering Education. April 23. Attendance 22.

University of Michigan

A film, showing the Okonite method of manufacturing insulated wires and cables, was shown. April 26. Attendance 30.

School of Engineering of Milwaukee

Standing Waves at Ultra-Radio Frequencies, by Ben Chromy. A motion picture, entitled "White Coal," was shown. April 20. Attendance 41.

Inspection trip to the Nash Motors Corporation. April 28. Attendance 40.

Motion pictures, entitled "The Audion" and "The Go-Getter," were shown. May 11. Attendance 25.

University of Minnesota

The Application of Synchronous Machines, by C. W. Place General Electric Co. March 9. Attendance 75.

Montana State College

Diesel-Electric Drive for Dredges, by B. W. Crowell, and

Lighting-Generator Research, by R. K. Frazier. April 8. Attendance 159.

The Graduate Engineer and His Relation to the Industries, by Mr. Caples, The Anaconda Copper Mining Co. April 12. Attendance 172.

Modernized Dipping and Baking, by S. Thompson, and

Electric Refrigeration, by H. F. Dehler. May 6. Attendance 147.

University of Nevada

Business Meeting. The following officers were elected: President, George Fairbrother; Secretary-Treasurer, Cornelius Fort. April 26. Attendance 20.

College of the City of New York

Inspection trip to Interborough Power Plant. March 30. Attendance 23.

Electric Wave Filters, by A. Granich, Bell Telephone Laboratory. Illustrated with slides. April 22. Attendance 41.

Business Meeting. May 6. Attendance 13.

New York University

Business Meeting. October 15. Attendance 21.

Opportunities for the Electrical Engineering Graduate, by Dr. L. L. Arnold. October 29. Attendance 28.

Business Meeting. November 13. Attendance 32.

Distortion in Radio Receiving Sets and Loud Speakers, by A. Senauke. December 11. Attendance 19.

Turbo-Alternators, by J. Hemingson, General Electric Co. January 15. Attendance 42.

Business Meeting. April 20. Attendance 21.

Distortion Causes in Audio-Frequency Amplifiers, by Alexander Senauke, Popular Science Radio Laboratory. April 22. Attendance 27.

University of North Carolina

The Automatic Telephone, by J. C. Fred, student. February 25. Attendance 31.

A-C. Measurements with the Electron Tube, by J. D. Finklea. March 8. Attendance 26.

The Power Possibilities of Muscle Shoals, by H. C. Klingenschmitt. April 1. Attendance 28.

Interesting Phases of the Electrical Engineering Profession, by T. J. McManis, General Electric Co. Illustrated with slides. April 26. Attendance 54.

University of North Dakota

Electrification of the Virginia Railroad, by Leonard Dagen;

The Electrical Stethophone, by Thore Hawk, and

The Life of Michael Faraday, by H. W. Augustadt. April 19. Attendance 17.

Northeastern University

Inspection trip to the Simplex Wire and Cable Company. April 2. Attendance 40.

Dangers of Electrical Shocks, by A. E. Kennelly, Harvard University. April 29. Attendance 64.

Ohio Northern University

Business Meeting. October 14. Attendance 47.

Protective Apparatus, by Mr. Roth. November 19. Attendance 22.

Business Meeting. January 20. Attendance 23.

The Application of Electric Power to Auxiliary Drives in Central Stations, by Prof. I. S. Campbell. April 14. Attendance 20.

The Application of the Compound-Interest Formula to the Various Sciences, by Prof. Whitted. April 28. Attendance 21.

Ohio State University

A motion picture, entitled "Wizardy of Wireless," was shown. April 30. Attendance 112.

Opportunities for Engineers in Public-Utility Work, by E. C. Stone, Duquesne Power and Light Co. Joint meeting with A. S. M. E. May 7. Attendance 52.

Oklahoma Agricultural and Mechanical College

Business Meeting. October 21. Attendance 66.

The Telephone Business, by Mr. Boone. Four reels of motion pictures were shown. April 21. Attendance 68.

University of Oklahoma

How To Lose Your First Job, by F. G. Tappan. April 15. Attendance 23.

Oregon State Agricultural College

The Influence of Line Voltage upon Induction-Motor Characteristics, by C. H. Bjorquist and H. E. Rhoads;

The Effect of Three-Phase Transformer Connections on Induced Harmonics, by D. O. Bergey, E. E. Kearns and C. W. Leihy, and

The Characteristics of Distribution Transformers at High Overloads, by F. C. Mueller, C. R. McLean, B. E. Plowman, O. W. Hurd and W. W. Bonar. Illustrated with slides. April 9. Attendance 56.

Pennsylvania State College

Electric Locomotives, by O. K. Harlan. Illustrated with slides. Joint meeting with A. S. M. E. March 3. Attendance 60.

Smoker. The following officers were elected: President, F. F. Wilkins; Vice-President, E. H. Basehore; Secretary, E. Huggler; Treasurer, M. I. Allen. April 28. Attendance 45.

University of Pennsylvania

After College, What?, by C. K. West, General Electric Co., and C. H. Wellerjean, Westinghouse Electric and Mfg. Co. February 25. Attendance 62.

Business Meeting. April 14. Attendance 45.

University of Pittsburgh

Crystal Control of Radio Frequencies, by F. C. Hartman, student, and

Experiences at National Tube Co., by G. M. Jarrett, student. March 5. Attendance 24.

The Liberty Bridge, by V. R. Covell, Bureau of Bridges of Alleghany County. March 12. Attendance 24.

George Westinghouse, by D. G. Nesbit, student, and

Railroad-Signal Control, by Chas. Caveny, student. March 19. Attendance 28.

Opportunities with The Duquesne Light Co., by W. F. Young. March 26. Attendance 28.

Homestead Steel Company, by A. S. Brown. April 9. Attendance 25.

Industrial Engineering, by L. P. Alford. April 16. Attendance 26.

Talks by H. J. A. Cramer and E. E. Muerer, students. April 23. Attendance 26.

Talks by E. H. Powell and J. J. Pfeiffer, students. April 30. Attendance 26.

Purdue University

The World of Paper, by P. Y. Tumey, General Electric Co. Illustrated with slides and motion pictures.

Switchboards, by C. C. Adams, General Electric Co. April 13. Attendance 100.

Westinghouse—The Institution, by Prof. L. D. Rowell. April 27. Attendance 35.

Rensselaer Polytechnic Institute

Modern Induction Furnaces, by J. A. Seede, General Electric Co., and

The Design and Operation of Electric Furnaces, by F. W. Brooke, William Swindell and Bros. April 20. Attendance 65.

Rhode Island State College

Stresses in High-Speed Turbines, by Professor Brown. March 29. Attendance 21.

Rutgers University

Finances of the Light and Power Industry, by Mr. Siddons, student, and

The Treating of Telephone and Telegraph Poles, by Mr. Miller, student. April 19. Attendance 19.

South Dakota State School of Mines

Business Meeting. April 1. Attendance 11.

University of Southern California

The Duties of a Power Salesman, by Mr. King, Los Angeles Bureau of Power and Light, and

The Application of Electricity to the Oil Industry, by Mr. Wade. April 15. Attendance 37.

Stanford University

The Pit River Development of the Pacific Gas and Electric Co., by E. A. Crellin. Illustrated with slides. April 20. Attendance 26.

Business Meeting. May 4. Attendance 21.

Stevens Institute of Technology

A motion picture, entitled "Speeding Up Deep-Sea Cables," was shown. A short talk was also given by Lincoln Walsh, student. April 15. Attendance 74.

A film, illustrating the applications of the gyroscope, was shown. a demonstration of the properties of the gyroscope by means of a small model was also given by L. G. Walsh, student. The following officers were elected: Chairman, D. B. Wesstrom; Secretary, Gene Witham. May 4. Attendance 110.

Swarthmore College

Business Meeting. April 15. Attendance 30.

Syracuse University

A motion picture, entitled "Power," was shown. April 12. Attendance 19.

Automatic Railway Substations, by W. H. H. Wilkinson. April 19. Attendance 19.

Agricultural and Mechanical College of Texas

Electrical Show, produced by the students. In connection with the show the Southwestern Bell Telephone and Telegraph Company held a pageant showing the development of the telephone for the last 50 years. April 10. Attendance 1000.

Problems of Independent Telephone Companies of Today, by R. B. Still, Association of Independent Telephone Companies of Texas. May 7. Attendance 84.

University of Texas

A motion picture on Automatic Substation Control was shown. April 8. Attendance 23.

Business Meeting. April 22. Attendance 8.

Virginia Military Institute

The Socket Power Supply for Radio Receivers, by W. R. Noble. Motion picture, entitled "The Queen of the Waves," was shown. December 22. Attendance 19.

A motion picture, entitled "The King of the Rails," was shown. February 15. Attendance 47.

University of Virginia

Motion pictures, entitled "The King of the Rails," and "The Panama Canal," were shown. April 19. Attendance 16.

Communication from Moving Trains, by Jean Roberts. Motion pictures, entitled "The Go-Getter," and "The Queen of the Waves," were shown. May 3. Attendance 20.

University of Washington

The Design of Telephone Pole Lines, by Mr. Freed, Pacific Telephone and Telegraph Co. April 7. Attendance 22.

Worcester Polytechnic Institute

The Telephone, by Captain J. C. Fair, New England Telephone and Telegraph Co. April 21. Attendance 28.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers cooperating with the Western Society of Engineers. The service is available only to their membership, and is maintained as a cooperative bureau by contributions from the societies and their individual members who are directly benefited.

Offices:—33 West 39th St., New York, N. Y.,—W. V. Brown, Manager.
53 West Jackson Blv'de., Room 1736, Chicago, Ill., A. K. Krauser, Manager.
57 Post St., San Francisco, Calif., N. D. Cook, Manager.

MEN AVAILABLE.—Brief announcements will be published without charge but will not be repeated except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of \$3 per quarter, or \$10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of \$10 for all positions paying a salary of \$2000 or less per annum; \$10 plus one per cent of all amounts in excess of \$2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

ELECTRICAL SWITCH DESIGNER, for automatic control of direct- and alternating-current motors. Opportunity. Apply by letter stating technical training, experience, age and required salary. Location, New York City. R-9039.

ELECTRICAL ENGINEER GRADUATES, two, with several years' experience, for distribution department of large public utility. Opportunity to enter commercial sales department. Experience in overhead distribution layout and estimating desirable. Opportunity. Apply by letter with complete details of age, education, training, experience and salary desired with recent photograph. Location, Middle Atlantic. R-9727-C.

INSTRUCTOR, electrical engineering graduate, under 30, to instruct in lecture room and laboratory educational department of large eastern public utility. Some experience in pedagogy and the electrical industry essential. Apply by letter, stating education, experience, age, salary expected, and other details. Location, New York City. R-9068.

MEN AVAILABLE

1925 GRADUATE ELECTRICAL ENGINEER, Georgia Tech., age 24, sales and business experience. Desires position with possibilities for advancement with public utility or electrical contracting company. Location, preferably Florida or Georgia. C-2004.

PLANT ENGINEER, MECHANICAL SUPERINTENDENT OR MASTER MECHANIC, mechanical engineer, age 40, with fifteen years' experience in the above, desires an opening with a progressive concern. Prefers location in Eastern or Central states. C-1182.

ELECTRICAL ENGINEER with wide and thorough experience in America and Europe, desires position as executive or chief electrical engineer. Competent in electrical and mechanical design of electrical machinery; made special study of gasoline electric automotive vehicles. Familiar with research work in electrical, mechanical and physical problems. East preferred. Minimum salary $6600. C-693.

ENGINEER, age 36, married, graduate M. E. and E. E., wide range of engineering experience, and especially well qualified in public utility electrical engineering, power plants, sub-station lines. Highly trained technically, but prefers position requiring combination of technical and executive ability. Available in two to four weeks. Location, United States. B-5842.

ELECTRICAL ENGINEER, age 32, married, technical graduate, ten years' experience in construction, maintenance and hydroelectric work with prominent companies here and in Venezuela, South America. Desires permanent position in Spanish speaking country. Available on short notice. C-917.

ELECTRICAL ENGINEER, four years' design and development experience with large manufacturing company. Would like similar work with a well established company in the Middlewest. College graduate, 28, married. C-1132.

EXPERIENCED ENGINEER, age 40, single, desires investigational work, preferably of electrical and mechanical laboratory research or development type. Ability tested in many ways. Reports on problems requiring originality and resourcefulness, and the supervision of others, most satisfactory. Available after May 15, 1926. Location preferred, Middlewest. B-6273.

ELECTRICAL ENGINEER, technical graduate, ten years' experience with large Eastern manufacturing concern, desires position as instructor in department of electrical engineering. Qualified to teach direct and alternating current machinery, and electrical laboratory. Especially interested in laboratory work. Position must offer possibilities of advancement. Location, West. C-50.

ASSISTANT EXECUTIVE, well balanced experience of thirteen years on cost analysis, industrial processing, commercial statistics, advertising administrative control. Seven years with large company servicing subsidiaries and clients. Public utility experience. Prefers administrative or commercial to strictly technical. Technical graduate, married, 34. Location, New York, New England. Available reasonable notice. B-9122.

ELECTRICAL ENGINEER, age 24, will graduate in June 1926. Interested in sales or distribution of some technical product. C-1306.

CONSTRUCTION ENGINEER, age 38, married, electrical graduate, recent study M. I. T. Allis Chalmers test. Thirteen years' experience electrical manufacture, installation power plant machinery, maintenance, general construction. Desires position steam plant construction. Salary $3600. Available June 1st. A-4018.

TECHNICAL GRADUATE OF BRITISH UNIVERSITY, electrical engineering, age 35, single, over ten years' experience in general electrical and mechanical engineering, including lighting installations, one year illumination tests, about three years mechanical drafting, inspection of finished parts, also two years' experience in patent disclosures and patent drafting. Besides English, speaks and writes two Balkan languages and French. Inventive abilities. Best references. Willing to go anywhere. B-7214.

RADIO COMPASS ENGINEER, technical graduate, desires position with reliable concern in this capacity. Present employed by U. S. Navy Department on position and direction finding by radio. C-723.

ELECTRICAL ENGINEER, B. S. in railway electrical engineering in 1924, 23, single. Two years in general engineering course; two years in central station and substation work in large Midwestern utility engineering department. Location desired, Illinois or foreign. C-1331.

INSTRUCTOR, age 28, single, B. S. and M. S. in E. E., ('23 and '24). Now taking graduate courses in mathematics. Experience; nine months time study and job analysis with an electrical manufacturer, ten months training course in generating and distributing departments of a public utility. Ready to begin about September 6th. C-1034.

ASSISTANT PROFESSORSHIP desired by an electrical engineer seeking promotion above present position. Age 30, married, three years' practical and five years' teaching experience. B. S. and M. S. degrees in electrical engineering. Man of initiative and ability. Desires position in recognized Eastern or Midwestern university. B-3376.

ELECTRICAL ENGINEER, expert switchboard designer, power station layout, relay protection, selection of oil circuit breakers and automatic switching. South West preferred. C-1333.

ELECTRICAL ENGINEER, age 27, experience in research and developing of electrical appliances, desires similar employment. Available on two weeks' notice. Salary $250 a month. B-7270.

ELECTRICAL ENGINEERING GRADUATE, age 31, married, eight years' experience in engineering research, development and teaching electrical theory and laboratory. Graduate study carried on while teaching. Available at once for continuing in similar work. C-3.

SALES ENGINEER, age 34, married, well acquainted with New England markets, desires to represent electrical manufacturer in this territory. Experienced in selling to dealers, jobbers and manufacturers. Technical education. Ten years' Engineering and selling experience. Present connection with internationally known manufacturer. Salary and expenses. Available one month. A-1330.

LICENSED PROFESSIONAL ELECTRICAL ENGINEER, versed also in mechanical, structural steel, concrete and hydraulic work. Power stations, power transmission, industrial plants, etc. Design, construction, operation; practical as well as theoretical (research). Reliable, responsible. B-7337.

RADIO ENGINEER, thoroughly educated, experienced, wants position technical correspondent or development engineer large radio company. Past four years employed as operating engineer, second in charge, in two of New York's broadcasting stations. Designed, constructed, installed third large broadcasting station Second Radio District. Two years magazine, special feature writing experience. Not interested position broadcasting station. Available two weeks' notice. Minimum salary $3000. C-1108.

ELECTRICAL ENGINEER, age 29, married, university graduate, five year course, one year in Commerce and Journalism College. Desires connection with progressive company in commercial capacity or industrial engineering firm. Work has covered estimating, contracting and manufacturing work. Available on reasonable notice. Location, Ohio. B-9865.

MECHANICAL ENGINEER, technical graduate, married, wide experience in design and construction of power plants, fire prevention and protection, and preparation of special reports, extensive acquaintance among city officials. Desires position with contractor or consulting engineer. B-7189.

ELECTRICAL ENGINEER, age 30, married, graduate E. E. M. E. Seven years' varied experience on central and substation estimating, design, construction and installation also safety and research work. Five years in responsible positions with private corporation and public utilities. Good record and references. Desires responsible position requiring ingenuity and good judgment with industrial, engineering or small power company, preferably New York or neighboring state. Available on reasonable notice. B-5505.

ASSISTANT ENGINEER, age 25, single, electrical and mechanical. Eight year course engineering theory and electrical station design. Apprenticed motor and generator building. Installed and repaired gas and crude oil engines, automatic lighting and pumping systems, machinery, etc. Available on seven days' notice. C-1301.

GRADUATE ELECTRICAL ENGINEER, will go anywhere; over twelve years' experience in construction, operation, maintenance of steam generating stations; efficient production of power; meter and installation work. Desires post leading to executive responsibility. Knowledge Spanish. Age 38. Married. $4200 minimum. Available August. C-1372.

ELECTRICAL ENGINEER, COLLEGE GRADUATE. Seventeen years' experience on power station, sub-station, transmission and industrial work as designer, chief draftsman, assistant engineer. Experience with manufacturing companies, Public Utilities and Consulting Engineers. B-7183.

ELECTRICAL construction, maintenance or appraisal engineer, wide experience in construction work including steam turbine installations, largely with electric manufacturing and public utility companies. Competent to make up prices for public utility appraisals. C-1163.

ELECTRICAL ENGINEERING GRADUATE, 29, single, wishes position with engineering or construction firm where the following experience can be used to advantage. Two years' experience on bridges, conveyer equipment, one year test and assembly electrical motors, one one year test and assembly storage batteries. Great adaptability. Hard worker, available immediately. Location, Northern Ohio preferred. B-7908.

GRADUATE ELECTRICAL ENGINEER. Special studies Business Administration—four years varied experience with large manufacturing company and as technical assistant to electrical superintendant large steel company in charge of maintenance and construction. Familiar with all details of the department including estimates, power distribution, tests, and personnel. Excellent references from former employers. C-1297.

ELECTRICAL ENGINEER, age 26, married, technical graduate, four years' experience test supervision with public utility, one year's experience teaching, executive, statistician, organizer. Desires position with progressive organization offering reasonable advancement for conscientious, energetic worker. C-1346.

ELECTRICAL ENGINEER, M. I. T. graduate, two years' active experience in telephone engineering. Desires position with a future with manufacturing company on production, technical, or sales staff. Location, vicinity of New York. Available two weeks. C-1305.

ELECTRICAL and mechanical engineer, university graduate, age 39, married, desires executive or sales position. Twelve years' executive experience, electric railway, light and power. Wide acquaintance among operating officials of all utilities, and manufacturers. Best references. Available May 1st. New York vicinity preferred. C-1235.

ENGINEER, B. S. and E. E. degrees, fifteen years' experience testing, construction, design and supervision of substation and distribution work. Desires connection with manufacturer, public utility, engineer or investment banker employing engineers. Available on one month's notice. B-9551.

ELECTRICAL GRADUATE, age 24, single, desires permanent position engineering work. One year test, one year Caines current field engineering with General Electric Company. Familiar with Utilities of the South. C-1391.

ELECTRICAL ENGINEER, college and technical graduate, age 25 years' broad experience in power plant and substation design, H. T. bus construction, power and light distribution, underground and line transmission, quantity surveys, specification writing, executive correspondence, and office charge desires position with reliable utility company, Atlantic coast preferred. B-3231.

ELECTRICAL ENGINEER, age 26, married, desires position that has good chance for advancement. Fifteen months with General Electric Company as student engineer, two years teaching electrical engineering, three months operating large hydro-electric plant. Available at once. C-54-100.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED MAY 21, 1926

ALBISTON, WILLIAM AARON, Radio & Electrical Engineer, Christmas Island Phosphate Co., Christmas Island, Indian Ocean.

ALLEN, THOMAS DANIEL NORRIS, Elec. Engg. Draftsman, U. S. Veterans' Bureau, Arlington Bldg., Washington, D. C.

*ANDREWS, SIDNEY WARREN, Engineer, Foundation Co., Pittston, Pa.

BALLEW, RICHARD E., System Dispatcher, Great Western Power Co., 3729 Park Blvd., Oakland, Calif.

BANTON, FOWLER BOYNTON, Electrical Engineer, New Orleans Public Service Co., 201 Baronne St., New Orleans, La.

BECKER, FRED A., Sale Engineer, Canadian General Electric Co., 212 King St., West, Toronto, Ont., Can.

BERTING, GERALD A., Asst. Sales Manager, The North Electric Mfg. Co., Galion, Ohio.

BLENKARN, WILLIAM O., Electric Plant Operator, Salt Creek Electric Plant, Midwest, Wyoming.

BODELSSON, ALFRED, Pratt Institute, 210 Grand Ave., Brooklyn, N. Y.

BOLLINGER, NEWTON H., Distribution Engineer, Florida Power and Light Company, Miami, Fla.

BOYD, J. W. G., Jr., Engg. Dept., Canadian National Carbon Co., Toronto, Ont., Can.

BRAUN, ALFRED WILLIAM, Secretary & Treasurer, William Braun & Co., 30 Church St., New York; res., Glendale, N. Y.

BRESSNER, JOSEPH, Student, Pratt Institute, Brooklyn, N. Y.

BROWN, HAROLD HASLEY, Electrical Engineer, Wisconsin Traction, Light, Heat & Power Co., 112 E. College Ave., Appleton, Wis.

BROWN, RALPH EUGENE, Instructor, Mechanical Engg. Dept., Rhode Island State College, Kingston, R. I.

BUCHANAN, THOMAS, Engineer, The British Thomson-Houston Co., Ltd., Neasden Lane, Willesden, res.; Harlesden, London, N. W. 10, England.

BURDIN, ALBERT JOHN, Equipment Engineer, Western Electric Co., Hawthorne Sta., Chicago, Ill.

BURKHARDT, CHRISTIAN ERWIN, Supt., Municipal Power & Ice Plant, Sebastian, Fla.

CADY, WILLIAM MALCOLM, Development Work, 108 Clinton Ave., Newark, N. J.

CAROLAN, WILLIAM ALFRED, 712 Putnam Ave., Brooklyn, N. Y.

CARPENTER, HAROLD WAIT, Salesman, Sangamo Electric Co., 19 Pearl St., Boston, Mass.; res., Norwich, Conn.

CATES, ROBERT VERNOR, Transmission Man, American Tel. & Tel. Co., Charlotte, N. C.

CHANT, ARTHUR E., Chief Accountant, Dept. of Telephones, Telephone Bldg., Regina. Sask., Can.

CLARK, OLPHA SIMPSON, Engineer, Transmission Dept., Union Gas & Electric Co., 2016 Dana Ave., Cincinnati, Ohio.

CLARKE, PHILIP CORLISS, Draftsman, General Electric Co., 6801 Elmwood Ave., West Philadelphia; res., Philadelphia, Pa.

COLVIN, A. L., Dist. Supt., Niagara Lockport & Ontario Power Co., Angola, N. Y.

CRAWFORD, WILLARD K., Tester, Brooklyn Edison Co., 360 Pearl St., Brooklyn, N. Y.

CSEPELY, JOHN ANTHONY, Electrical Engineer, The Western Electric Co., Inc., 268 W. 36th St., New York, N. Y.; res., Guttenberg, N. J.

DAVIS, ALBERT EDWARD HARRY, Electrical Engineer, Frank J. Yorke Co., 159 Elizabeth Ave., E., Detroit, Mich.

DAVIS, HARRY FRANKLIN, Electrician, Monongahela West Penn Public Service Co., Bethlehem Bldg., Fairmont, West Va.

DeDONA, ANTHONY JOSEPH, Plant Supervisor, Postal Telegraph Co., 253 Broadway, New York, N. Y.

de POLAC, LEON C., Sales Correspondent, Westinghouse Elec. & Mfg. Co., 150 Broadway, New York, N. Y.

de ZAMACONA, LUIS, Testing Engineer, Mexican Light & Power Co., 20 Gante St., Mexico City, Mex.

DOWNIE, CHRISTOPHER GORDON, Metropolitan-Vickers Electrical Co., Ltd., Manchester; res., Sale Cheshire, Eng.

DUNCANSON, PETER, Electrician, Western Electric Co., Kearny; res., Jersey City, N. J.

DUNSTAN, RUSSELL ALFRED, Student Engineer, General Electric Co., Schenectady, N. Y.

EIGHMY, GEORGE WELLS, Electrical Engineer, General Electric Co., 1100 Electric Bldg., Buffalo, N. Y.

ELLIS, CHARLES RUSSELL, Electrical Field Engineer, Louis T. Klauder, 1300 Bankers Trust Bldg., Walnut & Juniper Sts., Philadelphia; res., Bristol, Pa.

*ENGELKEN, RICHARD C., Field Surveyor, Brooklyn Edison Co., 360 Pearl St., Brooklyn; for mail, New York, N. Y.

ENGH, JAMES STONEHAM, Field Operating Engineer, Automatic Electric, Inc., 1033 W. Van Buren St., Chicago, Ill.

FARRELL, JAMES J., Caribou Power House, Great Western Power Co., Caribou, Plumas Co., Calif.

FELDMAN, JOSEPH JAY, Sales Engineer, Westinghouse Elec. & Mfg. Co., 160 7th St., Brooklyn, N. Y.

FERREIRA, AULIO CLEMENTE, Asst. Supt., Elec. Studies & Investigations, The Sao Paulo Tramway Light & Power Co., Ltd., R. Bento, Freitas 51, Sao Paulo, Brazil, S. A.

*FOLTZ, JOSEPH P., Student, Westinghouse Elec. & Mfg. Co., 1308 Center St., Wilkinsburg, Pa.

FORKEL, WALTER HEINRICH, Draftsman, Metropolitan Electr. Manufacturing Co., Boulevard & 14th St., Long Island City; res., Brooklyn, N. Y.

*FOSTER, HARRY BLISS, Tester, Wireless Specialty Apparatus Co., 76 Atherton St., Boston; res., Medford, Mass.

FOWLER, JAMES RICHMOND, Electrical Inspector, Westchester Lighting Co., Mt. Vernon; res., Brooklyn, N. Y.

GALER, FRANK CHARLES, Electrican, Lancashire Dynamo & Motor Co., 45 Niagara St., Toronto, Ont., Can.

*GERMAN, CORNELIUS, Instructor, Elec. Engg. Dept., College of Engineering, University of Philippines, Manila, P. I.

GLOVER, GEORGE C., Switchboard Operator, Chile Exploration Co., Chuquicamata, Chile, S. A.

*GRUENBERG, ANATOLE R., Junior Partner, W. T. Swoyer & Co., Taylor Bldg., Johnson City, Tenn; for mail, De Land, Fla.

HADDOCK, CHARLES COLVOCORESSES, Asst. Engineer, Brooklyn Edison Co., 55 Johnson St., Brooklyn, N. Y.

HAIG, CLINTON M., Engineer, New England Tel & Tel. Co., 50 Oliver St., Boston, res.; Arlington, Mass.

HANKEY, WILLIAM JOSEPH, Electrical Engineer, Cleveland Railway Co., 13404 Chapelside Ave., Cleveland, Ohio.

HARRINGTON, GEORGE W., Student, Industrial Elec. Engg., Pratt Institute, Ryerson St., Brooklyn, N. Y.

*HARRISON, ARTHUR TEMPLETON, Operator, Hat Creek No. 1, Pacific Gas & Electric Co., Cassel, Calif.

HARRISON, JOHN KEARSLEY MITCHELL, Engineer, Harrison & Co., 1824 Land Title Bldg., Philadelphia, Pa.

*HARTE, JOSEPH A., Mechanical & Electrical Draftsman, Dept. of Plant & Structures, Municipal Bldg., New York, N. Y.

HEINSTALL, WILLIAM GODFREY, Plant Supt., Lignite Utilization Board, Bienfait, Saskatchewan, Can.

HERBERS, HERMAN HEINRICH WILHELM, Asst. Engineer, New York Edison Co., 302 Ditmas Ave., Astoria, N. Y.

HINDMAN, EDWARD RUSSELL, Electrical Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

HOLLEMAN, ELWOOD MONROE, Radio Salesman, Germains, 6th & Main Sts., Los Angeles, Calif.

HOLTON, THEODORE R., American Steel & Wire Co., Cable Works, Worcester, Mass.

HUDSON, ALFRED, Student Engineer, General Electric Co., Schenectady, N. Y.

HUDSON, FLOYD EDWARD, Electrical Tester, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.

HUGHES, GRIFFITH OSBORNE, Chief Operator, Power Plant No. 2, Bureau of Power & Light, City of Los Angeles, Saugus, Calif.

ISHII, TADASHI, Electrical Engineer, Japanese Government Railways, 1 Madison Ave., New York, N. Y.

JONES, FRANK AUGUSTUS M., Chief Draftsman, The Pacific Tel. & Tel. Co., 140 New Montgomery Bldg., San Francisco, Calif.

JONES, JOHN PAUL, Consulting Engineer, 1740 E. 12th St., Cleveland, Ohio.

*JONES, RALPH WILLIAM, Distribution Engineer, Consumers Power Co., Flint; res., Clio, Mich.

JUND, DANIEL, Foreman, W. C. Lagerway, 181 West End Ave., Instructor, New York Electrical School, New York, N. Y.

KELHOFER, LEON MARTIN, Electrical Engineer, Commonwealth Power Corp., Jackson, Mich.

*KHALIFAH, ABD-EL-RAHMAN AMER, Mechanical Engg., Baldwin Locomotive Works, Broad & Spring Garden Sts., Philadelphia, Pa.

KIRKPATRIC, KENNETH JOHN, Supt., Telephone Cable Factory, Metal Manufactures Proprietary Ltd., Port Kembla, N. S. W., Aus.

KLEIN, FERNAND A., Engineer, Public Service Electric & Gas Co., 80 Park Place, Newark, N. J.

KOTHARE, MAHADES BAPUJI, Chief Engineer, Broach Electric Supply & Development Corp., Ltd., Broach, India.

KOVALSKY, JOSEPH FRANK, Electrical Engineer, Control Engg. Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Swissvale, Pa.

KOVEDIAEFF, BORIS E., 1018 W. 73rd St., Los Angeles, Calif.

KUPFERLE, ARTHUR TROMMER, Instrument Repair Man, Meter Laboratory, Union Gas & Electric Co., 1107 Plum St., Cincinnati, Ohio.

LAMANTIA. JOACHIM C., Student, Brooklyn Polytechnic Institute, Brooklyn; res., New York, N. Y.

LAPPIN, JOHN L., Electrical Draftsman, General Electric Co., 5 Lawrence St., Bloomfield, N. J.

LAUTH, EDWIN HARRY, Electrical Engineer, Street Lighting Section, City of St. Louis, City Hall, St. Louis, Mo.

LEWIS, FRANK M., Plant & Engg. Dept., Northwestern Electric Co., Portland, Ore.

LONGY, VINCENT, Resident Electrical Engineer, British Engine, Boiler & Electrical Insurance Co., Ltd., Barcelona, Spain.

MANNING, EDWARD RALPH, Sales Engineer, Weston Electrical Instrument Corp., 50 Church St., New York, N. Y.; res., Bayonne, N. J.

MARKOVITS, JOSEPH ARPAD, Draftsman, Westinghouse Elec. & Mfg. Co., 432 Meek St., Sharon, Pa.

MARSHALL, ARMOND EDWIN, Electrical Draftsman, The Philadelphia Electric Co., 23rd & Market Sts., Philadelphia, Pa.

MARTIROSIAN, MICHAEL M., Student, State College of Washington, Pullman, Wash; res., New York, N. Y.

McCULLOCH, HAROLD, Asst. Electrical Engineer, Hydro-Electric Dept., Hobart, Tasmania.

McGINNIS, NEIL W., Chief Electrician, Parafine Co.'s, Inc., Vernon & Santa Fe Aves., Los Angeles, Calif.

McGRATH, MARTIN HAGER, Research Laboratory Standard Underground Cable Co., 17th & Pike Sts., Pittsburgh, Pa.

McINTYRE, ROBERT JOSEPH, Asst. Service Manager, Gray Electro Chemical Laboratory, 9-11 W. 20th St., Bayonne; res., Jersey City, N. J.

*McKEON, JOHN BRICHER, Cadet Engineer, Elec. Dept., Rochester Gas & Electric Corp., Rochester, N. Y.

MILNE, KENNETH HARVEY, Commonwealth Power Corp., Jackson, Mich.

MIMMACK, ARTHUR, City Electrician, Engg. Dept., City Hall, Beverly Hills; res., West Hollywood, Calif.

MORORO, DORGIVAL GONCALVES, 3100 North Grand Blvd., St. Louis, Mo.

MOSS, JOHN E., Electrician, West Penn Power Co., Washington, Pa.

MURPHY, JOHN ANSON, Asst. to Elec. Supt., McClellan & Junkersfeld, Inc., St. Louis, Mo.

*NEMETZ, VICTOR W., Electrical Engineer, Commonwealth Power Corp., Jackson, Mich.

NERGES, FRANK ANTHONY, Electrician, U. S. N., U. S. S. Owl No. 2, N. O. B., Hampton Roads, Va.

NIXON, JOHN HUMPHREY RUSSELL, Electrical Machine Designer, Messrs, Brush Elec. Engg. Co., Ltd., Falcon Works, Loughborough, Leicestershire, Eng.

NOGUCHI, KOJU, Member of Research Staff, Mitcubishi Research Laboratory, 29 Kamifujimaecho, Komagome, Hongo, Tokyo, Japan.

O'SHEA, M. VINCENT, Jr., 529 N. Pinckney St., Madison, Wis.

OVERFIELD, G. BRYAN, Sales Engineer, Burke Electric Co., 12th & Cranberry Sts., Erie, Pa.

*PANTON, HARRY A., Engineer, Buffalo General Electric Co., Electric Bldg., Buffalo, N. Y.

PASAYIOTIS, GEORGE N., Proprietor, Book-News & Novelty Co., 852 Penn St., Reading, Pa.

PATEL, DAHYABHAI BAKORBHAI, Research Work, Indian Electrical Problems, c/o Brown Boveri & Co., Baden, Switzerland.

PETERSEN, HENRY N., Load Dispatcher, Great Western Power Co. of California, 3729 Park Blvd., Oakland, Calif.

PETERSON, JOHN REYNOLD, Radio Interference Inspector, Western Union Telegraph Co., 49 Geary St., San Francisco, Calif.

PETTIT, ZACHARY T., Underground Electrical Engineer, Los Angeles Gas & Electrical Corp., 810 S. Flower St., Los Angeles; res., San Gabriel, Calif.

PHELPS, MERRICK W., Dist. Manager, Pittsburgh Transformer Co., 601 Electric Bldg., Buffalo, N. Y.

PHILIPSON, RALPH E., Designer, Electric Bond & Share Co., 65 Broadway, New York, N. Y.

*PYLE, ALBERT JOCELYN, Instructor, Elec. Engg., Moore School of E. E., Univ. of Penna., Philadelphia, Pa.

RAGG, FRED C., Electrical Engineer, Textile Dyeing Co. of America, Paterson, N. J.

RANSFORD, HERBERT EARL, Sales Engineer, Henry N. Muller Co., 812 Westinghouse Bldg., Pittsburgh, Pa.

REIFSNYDER, SIDNEY EARLE, Supt. of Construction, Chas. Cory & Son, Inc., 15th & Venango Sts., Philadelphia, Pa.

REILLY, FRANCIS JOSEPH, Sales Engineer, Tork Co., 8 West 40th St., New York, N. Y.

ROBINSON, JOHN WILLIAM, Instrument Maker, Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia, Pa.

RODGERS, KARL F., Member, Technical Staff, Bell Tel. Laboratories, Inc., 463 West St., New York, N. Y.

ROSS, RAYMOND W., Drafting & Designing Dept., Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia, Pa.

ROYERE, JEAN EUGENE, Plant Operator, Electrical Testing Laboratories, 80th St. & East End Ave., New York, N. Y.

*SAMSON, DAVID FORSYTH, Electrical Contracting, 71 Chestnut St., Branford, Conn.

SCANLON, DALE LESTER, Electrical Foreman, Chile Exploration Co., Chilex, Chuquicamata, Chile, S. A.

SCHMELTZER, CAESAR FREDERICK, Specification Draftsman, Commonwealth Edison Co., 72 W. Adams St., Chicago; res., Cicero, Ill.

SCHOLZ, CHARLES BRADFORD, Plant Engineer, Interstate Utilities Co., 424 Hutton Bldg., Spokane, Wash.

SCHROEDER, EDWARD H., Division Supt., Installation Dept., Western Electric Co., Inc., 1505 Race St., Philadelphia, Pa.

SCOTT, THOMAS WEBB, Signal Supervisor, Baltimore & Ohio Railroad, Connellsville, Pa.

SISKIND, ROBERT PEER, Research Assistant, Elec. Engg. Dept., Harvard Engineering School, 204A Pierce Hall, Cambridge; res., Brookline, Mass.

SMITH, HAROLD L., Student Engineer, Southern Ontario Gas Co., Merlin, Ont., Can.

SNOW, HOWARD BARTLEY, Asst. Engineer, Public Service Production Co., 80 Park Place, Newark, N. J.

SNYDER, FRANKLIN L., Engineer, Transformer Engg. Dept., Westinghouse Elec. & Mfg. Co., Sharon; res., Sharpsville, Pa.

SPECTOR, BARUCH, Transformer Draftsman, Westinghouse Elec. & Mfg. Co., Sharon, Pa.

SPENCER, RIPLEY M., Electrical Inspector Los Angeles Gas & Elec. Co., 725 Channing St., Los Angeles, Calif.

STEEB, GEORGE, Asst. to Supt., Niagara Lockport & Ontario Power Co., Gardenville, N. Y.

STEINKAMP, WALTER, Distributor, X-Ray & Electro Medical Equipment, 253 Alexander St., Rochester, N. Y.

STEVENS, EDWARD JAMES, Jr., Inspector, Gurney Elevator Co., Inc., 300 8th Ave., New York, N. Y.; res., Belleville, N. J.

STINSON, MALCOLM JOSEPH, Relief Operator & Power Director, Montville Power Station, Uncasville, res., Norwich, Conn.

STUBBS, WALTER W., Electrical Repairman, Champion Coated Paper Co., Hamilton, Ohio.

SZAPPANYOS, ALEXANDER, Draftsman, Engg. Dept., Westinghouse Elec. & Mfg. Co., Sharon, Pa.

THOMAS, RALPH EDWIN, Commercial Engineer, Westinghouse Elec. & Mfg. Co., 1535 6th St., Detroit, Mich.

THOMPSON, WILLIAM SCOTT, Field Engineer, Michigan Bell Telephone Co., 1365 Cass Ave., Detroit, Mich.

TRACEY, FRANK S., Manager & Treasurer, Lockport & Newfane Pr. & Water Supply Co., 16 State St., Middleport, N. Y.

TRACY, GORDON FREDERICK, Instructor, Elec. Engg. Dept., University of Wisconsin, Madison, Wis.

TRAINOR, JOHN FRANCIS, Electrical Inspector, Underwriters Laboratories, 40 Central St., Boston; res., Fall River, Mass.

TURNER, WILLIAM FISHER, Employment Interviewer, Brooklyn Edison Co., Inc., 360 Pearl St., Brooklyn, N. Y.

WAGNER, VIRGIL CESAIRE, Electrical Estimator, Fischbach & Moore, Inc., 222 E. 42nd St., New York; for mail, Astoria, N. Y.

WASHBURN, JOHN C. B., Right-of-Way Dept., Narragansett Electric Lighting Co., Providence; res., East Greenwich, R. I.

WATLING, ROBERT GROVER, Engineer, Plant Dept., Southern California Telephone Co., 433 S. Olive St., Los Angeles; res., Glendale, Calif.

WATSON, H. KENNETH, Draftsman, Engg. Dept., Westinghouse Elec. & Mfg. Co., Sharon, Pa.

*WEINER, LOUIS, Anaconda Sales Co., 25 Broadway, New York, N. Y.

WEITZMAN, HARRY A., Penn Public Service Corp., Johnstown, Pa.

WESTBROOK, JOSEPH A. ALBERT, Engineer, Street Cable Div., Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

WILLIAMS, GEORGE SETH, Vice-President & General Manager, Central Maine Power Co., 317 Water St., Augusta, Me.

WILLIARD, JOHN ANDREW, Electrical Designer, Philadelphia Electric Co., 1035 Chestnut St., Philadelphia, Pa.

*WISSMANN, JOSEPH THEODORE, Receiving Engineer, Radio Corp. of America, Riverhead, N. Y.

WOMER, CLAUDE EMORY, Supt. of Equipment, Shamokin-Mt. Carmel Transit Co., Mt. Carmel, Pa.

WOODS, OSBORNE BAKER, Senior Operator, Newfoundland Power & Paper Co., Deer Lake, Newfoundland.

YOUNT, L. E., Asst. Manager, Western Radio, Inc., 1224 Wall St., Los Angeles, Calif.

ZEPLAIEV, PAUL PETER, Teacher, Elec. Engg. Dept., Polytechnic Institute of Leningrad, Leningrad, Russia.

ZIELINSKI, HEINZ, Draftsman-designer, Kny-Scheerer Corp. of America, 119 7th Ave., New York, N. Y.; res., Sharon, Pa.

ZIMMERMAN, EUGENE FREDERICK, Student Engineer, Southwestern Bell Tel. Co., 512 Planter's Bldg., St. Louis, Mo.

Total 161

*Formerly Enrolled Students.

ASSOCIATES REELECTED MAY 21, 1926

CRANSTON, ROBERT W., Supt. Substations, West Penn Power Co., 14 Wood St., Pittsburgh, Pa.

FLESHIEM, ROBERT STEPHENSON, Asst. Manager, Elec. Dept., Allis-Chalmers Mfg. Co., Milwaukee, Wis.

MAHOOD, EDWIN TERRELL, Valuation Engineer, Southwestern Bell Telephone Co., 569 Boatman's Bank Bldg., St. Louis, Mo.

MEMBER REELECTED MAY 21, 1926

SIMPSON, FRANK, Treasurer, The Collier-Simpson Co., 500 East 102nd St., Cleveland, Ohio.

MEMBERS ELECTED MAY 21, 1926

ALLEN, THOMAS SIMMONS, Engineer, Allis-Chalmers Mfg. Co., 3421 Sycamore St., Milwaukee, Wis.

BARNARD, GLENN HARRISON, Manager, Marine Sales & Philadelphia Dist. Office, Electro-Dynamic Co., Bayonne, N. J.

BECKETT, WILLIAM, Asst. Engineer, Dept. of Development, Georgia Railway & Power Co., Atlanta, Ga.

BURRI, JOSEPH JOHN, Supt. of Distribution, Staten Island Edison Corp., Staten Island, N. Y.

CASTER, JOHN HERBERT, Dist. Engineer, Hydro-Electric Power Commission of Ontario, 190 University Ave., Toronto, Ont., Can.

FLORY, A. C., Manager, Steam Turbine Dept., Allis-Chalmers Mfg. Co., Milwaukee, Wis.

HARVEY, ARTHUR FREDERIC, Asst. Engineer of Electrification, Central Argentine Railway, Victoria, F. C. C. A., Argentina, S. A.

HOADLEY, HERBERT EUGENE, Distribution Supt., The Ohio Public Service Co., Warren, Ohio.

LEWIS, HAROLD G., Springfield Service Manager, Westinghouse Elec. & Mfg. Co. 395 Liberty St., Springfield, Mass.

McLEAN, JAMES SINCLAIR, Construction Supt., The J. G. White Engineering Corp., 43 Exchange Place, New York, N. Y.

SCHOLZ, CARL E., Chief Engineer, Federal Telegraph Co., Palo Alto, Calif.

SPELLMIRE, WALTER B., Manager, General Electric Co., 1307 Oliver Bldg., Pittsburgh,, Pa.

THOMAS, WILLIAM ANDREW, 3rd Radio Engineer, Sonora Phonograph Co., Inc., 279 Broadway, New York; res., Brooklyn, N. Y.

THOMSON, OSCAR ROLAND, Asst. Supt., C. O. S., Hydro-Electric Power Commission of Ontario, Belleville, Ont., Can.

TRETJAK, GREGORY TIMOTHY, Teacher, Elec. Engg. Dept., Electrotechnical Institute, Pessotchnaya 5, log. 6, Leningrad, Russia.

UPP, JOHN W., Jr., Electrical Engineer, Ohio Brass Co., Mansfield, Ohio.

WILLISON, JOHN WRIGHT, Supt., Yorkshire Electric Pr. Co., 36 Park Place, Leeds, Yorkshire, Eng.

FELLOW ELECTED MAY 21, 1926

KLOSS, MAX, Prof. of Elec. Engg., Technische Hochschule, Charlottenburg; for mail, Berlin-Nikolassee, Germany.

TRANSFERRED TO GRADE OF FELLOW MAY 21, 1926

DWIGHT, HERBERT BRISTOL, Professor, Massachusetts Institute of Technology, Cambridge, Mass.

HEINZE, CARL A., Electrical Engineer in charge of Distribution, Department of Water & Power, City of Los Angeles, Los Angeles, Calif.

OEHLER, ALFRED G., Editor — *Railway Electrical Engineer*, Electrical Editor — *Railway Age*, New York, N. Y.

TRANSFERRED TO GRADE OF MEMBER MAY 21, 1926

ANDERSON, EDWARD T., Electrical Engineer, Board of Water & Electric Light Commissioners, Lansing, Mich.

BACKUS, CYRUS D., Principal Examiner, U. S. Patent Office, Washington, D. C.

BOHNERT, ARTHUR M., District Engineer, Ohio Brass Co., San Francisco, Calif.

BOLLINGER, HOWARD M., Supervisor of Plant Methods, Chesapeake & Potomac Telephone Co., Washington, D. C.

BROCKWAY, R. M., Engineer, Switchboard Dept., General Electric Co., Schenectady, N. Y.

CARPE, ALLEN, Engineer, Dept. of Development & Research, American Telephone & Telegraph Co., New York, N. Y.

CLAPP, ROBERT H., Telegraph Engineer, American Telephone & Telegraph Co., New York, N. Y.

COLBURN, WELLEN H., Electrical Engineer, Station Engineering Dept., Edison Electric Illuminating Co. of Boston, Boston, Mass.

FINCH, WILLIAM G. H., Radio Editor and Engineer, International News Service, New York, N. Y.

GIBSON, E. S., Telephone Engineer, Bell Telephone Laboratories, New York, N. Y.

JACKSON, DUGALD C., Jr., Asst. Professor of Electrical Engineering, Trinity College, Durham, N. C.

RAMIREZ, JAVIER P., Consulting Engineer, Professor Escuela de Ingenieros Mecanicos Electricistas, Mexico City, Mex.

RORTY, M. C., President, International Telephone Securities Corp. — Vice-President, International Tel. & Tel. Corp., New York, N. Y.

SAATHOFF, GEORGE W., Chief Construction Engineer, Henry L. Doherty & Co., New York, N. Y.

SPORN, PHILIP, Assistant to Electrical Engineer, American Gas & Electric Co., New York, N. Y.

SPRACKLEN, EMERY E., Electrical Engineer in charge of Design, Ohio Public Service Co., Massillon, Ohio.

TAYLOR, NEWTON S., Manager, Switchboard Section Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

WHIPPLE, CLYDE C., Asst. Professor of Electrical Engineering, Polytechnic Iustitute, Brooklyn, N. Y.

RECOMMENDED FOR TRANSFER

The Board of Examiners, has recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the National Secretary.

To Grade of Fellow

FONDILLER, WILLIAM, in charge, General Development Laboratory, Bell Telephone Laboratories, New York, N. Y.

HUBLEY, GEORGE W., Consulting and Advisory Engineer, Louisville, Ky.

STRENG, LEWIS S., Vice-President in charge of Operation, Louisville Gas & Electric Co., Louisville, Ky.

To Grade of Member

AMES, NORMAN B., Assistant Professor of Electrical Engineering, George Washington University, Washington, D. C.

BAILEY, RAYMOND, Chief Electrical Designer, Philadelphia Electric Co., Philadelphia, Pa.

CELIS, ATILIO, Manager-Engineer, San Juan Office of International General Electric Co., Inc., San Juan, P. R.

CHADWICK, RALPH H., Section Head, Transformer Engineering Dept., General Electric Co., Fort Wayne, Ind.

CLEARY, LEO H., Electrical Engineer, Standard Engineering Co., Washington, D. C.

EDISON, OSKAR E., Associate Professor of Electrical Engineering, University of Nebraska, Lincoln, Neb.

FEDER, JOSEPH B., Electrical Engineer, Chas. Cory & Son, Inc., New York, N. Y.

GARRISON, DWIGHT, Supt., Telephone Dept., Atlantic Refining Co., Philadelphia, Pa.

GAYLORD, JOHN C., Electrical Engineer' Southern California Edison Co., Los Angeles, Calif.

GORDON, LESLIE B., Chief Electrical and Power Engineer, Kelly-Springfield Tire Co., Cumberland, Md.

HALPENNY, R. H., Electrical Engineer, Southern Sierras Power Co., Riverside, Calif.

HAMILTON, JAMES T., Supt. of Equipment, New York, Westchester & Boston R. R., New York & Stamford Ry. Co., Westchester Street Ry. Co., New York, N. Y.

HECHT, J. BERNARD, Outside Plant Engineer, Tri-State Tel. & Tel. Co., St. Paul, Minn.

HESTER, EDGAR A., Transmission Planning Engineer, Duquesne Light Co., Pittsburgh, Pa.

HOWK, CLARENCE L., Telephone Engineer, International Standards Electric Corp., New York, N. Y.

KARCHER, E. KENNETH, Chief Electrical Engineer, Utica Gas & Electric Co., Utica, N. Y.

KENNEDY, S. M., Vice President, Southern California Edison Company, Los Angeles, Cal.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before June 30, 1926.

Alberti, J. N., General Electric Co., Schenectady, N. Y.

Allen, J. G., Duquesne Light Co., Pittsburgh, Pa.

Ames, A. W., Lighting Dept., City of Seattle, Seattle, Wash.

Auten, L. D., Cleveland Railway Co., Cleveland, Ohio

Ballantine, R. A., Penn Electrical Engineering Co., Scranton, Pa.

Ballard, W. C., Jr., Cornell University, Ithaca, N. Y.

Banan, H. F., Westinghouse Elec. & Mfg. Co., Boston, Mass. (Applicant for re-election.)

Barse, J. H., McKinney Steel Co., Cleveland, Ohio

Bartholomew, F. J., Bartholomew, Montgomery & Co., Ltd., Vancouver, B. C.

Barton, S., Federal Telegraph Co., Clearwater, Calif.

Bayles, C. G., Black & Veatch, Kansas City, Mo.

Becker, H., Jr., Interborough Rapid Transit Co., New York, N. Y.

Beckett, R. V., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Bennett, J. W., Eastern N. J. Power Co., Allenhurst, N. J.

Bergholtz, H., General Electric Co., Schenectady, N. Y.

Binder, G. A., Ohio Brass Co., Chicago, Ill.

Blake, F. J., Public Service Co. of Colorado, Denver, Colo.

Bodge, H. H., (Member), Fall River Electric Light Co., Fall River, Mass.

Borgeson, S. E., Western Electric Co., Inc., Hawthorne Sta., Chicago, Ill.

Bornholz, F. J., (Member), Shanghai Municipal Council, Shanghai, China. (For mail, San Francisco, Calif.)

Bothwell, F. A., General Electric Co., Schenectady, N. Y.

Boyere, E. E., (Member), Electrical Specialist, Erie, Pa.

Brackett, N. W., Puget Sound Power & Light Co., Seattle, Wash.

Braithwaite, W. S., Edison Elec. Illuminating Co., Boston, Mass. (Applicant for re-election.)

Brennon, L. A., General Electric Co., Erie, Pa.

Bristow, T. N., H. B. Squires Co., Seattle, Wash.

Brown, J. F., Tri-State College, Angola, Ind.

Brown, L., City of Seattle, Lighting Dept., Seattle, Wash.

Buchanan, E. C., The Pacific Tel. & Tel. Co., Portland, Ore. (Applicant for re-election.)
Burckett, D. M., Great Northern Railway, Seattle, Wash.
Burrow, P., Supt. of Power Plant, Dryden, Wash.
Bustillo, F. E., Mexican Light & Power Co., Mexico D. F., Mex.
Butler, W. C., The Pacific Tel. & Tel. Co., Seattle, Wash.
Butow, F. W. C., Pacific Coast Steel Co., S. San Francisco, Calif.
Butt, F. H., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Campbell, T. L., Toronto Hydro-Electric System, Toronto, Ont., Can.
Carrick, J. F. C., General Electric Co., Niagara Falls, N. Y.
Carter, T. B., Cumberland Tel. & Tel. Co., Louisville, Ky. (Applicant for re-election.)
Chambers, H. D., Puget Sound Power & Light Co., Seattle, Wash.
Christianson, E. C., Puget Sound Power & Light Co., Tacoma, Wash.
Cirella, L. E., Simplex Wire & Cable Co., Cambridge, Mass.
Cooper, R. F., Miller Rubber Co., Akron, Ohio
Crago, P. H., Union Switch & Signal Co., Swissvale, Pa.
Craven, F. E., Bell Telephone Co. of Pa., Philadelphia, Pa.
Crawford, J. M., General Electric Co., Schenectady, N. Y.
Crock, I. Z., New England Tel. & Tel. Co., Boston, Mass.
Crump, L. W., Puget Sound Power & Light Co., Tacoma, Wash.
Cunningham, K. G., Ohio Bell Telephone Co., Cleveland, Ohio
Curtis, G. V., General Electric Co., Schenectady, N. Y.
Cuthbert, J. T., Duquesne Light Co., Pittsburgh, Pa.
Davis, W., Toronto Hydro-Electric System, Toronto, Ont., Can.
Day, W. P., General Electric Co., Schenectady, N. Y.
de Lima, C. A., Westinghouse Elec. International Co., Mexico, D. F.
Denegen, R. J., Ohio Brass Co., Chicago, Ill.
de Vries, B. D., Duquesne Light Co., Pittsburgh, Pa.
Dibblee, J., (Member), Hydro-Elec. Pr. Commission of Ontario, Toronto, Ont., Can.
Diehl, W. A., National Malleable & Steel Castings Co., Cleveland, Ohio
Doane, P., New York Edison Co., New York, N. Y.
Dowe, G. P., The Canadian Crocker-Wheeler Co., St. Catharines, Ont., Can.
Drake, R. A., U. S. S. Arizona, San Francisco, Calif.
Duevel, C. O., Jr., Consumers Central Heating Co., Tacoma, Wash.
Duffy, L., Puget Sound Power & Light Co., Seattle, Wash.
Eveland, G. H., Feather River Power Co., San Francisco, Calif.
Fagan, H. J., 1555 Walton Ave., Bronx, New York, N. Y.
Falk, V. E., Stone & Webster, Inc., Boston, Mass.
Falor, H. L., Northern Ohio Power & Light Co., Akron, Ohio
Flory, C. L., Radio Corp. of America, Tuckerton, N. J.
Fontaine, J., North Carolina State College, Raleigh, N. C.
Forsyth, J. W., Engineer, City of Philadelphia, Philadelphia, Pa.
Free, J. E., General Electric Co., Philadelphia, Pa.
Fuhs, R. H., Indianapolis Light & Heat Co., Indianapolis, Ind.
Gale, Arthur P., Wisconsin Power & Light Co., Madison, Wis.
Gantenbein, E. F., Puget Sound Power & Light Co., Olympia, Wash.
Garner, F. E., Daven Radio Corp., Newark, N. J.
Ghen, M. W., Duquesne Light Co., Pittsburgh, Pa.
Giangrande, D. M., The New York Edison Co., New York, N. Y.
Gibney, E. L., Lighting Dept., City of Seattle, Seattle, Wash.
Gibson, F. C., Edison Storage Battery Co., Seattle, Wash.
Gillis, M. D., General Electric Co., Erie, Pa.
Gilson, W. J., Canadian & General Finance Co., Toronto, Ont., Can.
Goyne, T. S., Goyne Steam Pump Co., Ashland, Pa.
Graul, E. A., Duquesne Light Co., Pittsburgh, Pa.
Graves, J. M., (Member), Duquesne Light Co., Pittsburgh, Pa.
Hall, I. E., Roller-Smith Co., Bethlehem, Pa.
Hansen, T. A., Puget Sound Power & Light Co., Seattle, Wash.
Harkins, P. S., Bell Telephone Co. of Pa., Philadelphia, Pa.
Harrell, F. E., Reliance Electric & Engineering Co., Cleveland, Ohio
Hartle, W. G., General Electric Co., Schenectady, N. Y.
Haskens, A. J., Union Switch & Signal Co., Swissvale, Pa.
Helander, W. N., Puget Sound Power & Light Co., Olympia, Wash.
Hicks, L. V., (Member), Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Hillock, J. F., Duquesne Light Co., Pittsburgh, Pa.
Hite, J. W., Reliance Electric & Engineering Co., Cleveland, Ohio
Hoehn, E. H., Union Electric Light & Power Co., St. Louis, Mo.
Hults, The Ohio Public Service Co., Warren, Ohio
Hurlburt W. O., Gas & Electric Service Co., Chico, Calif.
Hyams, L. B., Gothem Electric & Supply Co., New York, N. Y.
Hyle, L. C., Emaus Telephone Co., Emaus, Pa.
Ishikawa, K., International General Electric Co., Schenectady, N. Y.
Jayne, J. K., Autocar Co., Brooklyn, N. Y.
Johnson, E. L., H. B. Squires Co., Seattle, Wash.
Johnson, R. H., Puget Sound Power & Light Co., Bremerton, Wash.
Johnson, R. R., Duquesne Light Co., Pittsburgh, Pa.
Keefer, J., Pacific Coast Steel Co., S. San Francisco, Calif.
Kellers, C. F., General Electric Co., Schenectady, N. Y.
Kepple, K. A., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Kilbury, W. A., Cleveland Elec. Illuminating Co., Cleveland, Ohio
Kincaid, M. B., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Klingenberg, F., Thomas E. Murray, Inc., New York, N. Y.
Knaus, F., Lighting Dept., City of Seattle, Seattle, Wash.
Krauskop, V. O., American Electric Power Co., Philadelphia, Pa.
Laube, L. F., General Electric Co., Schenectady, N. Y.
Lavo, K. E., General Electric Co., Schenectady, N. Y.
Lindstrom, C. T., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Linton, S., Stone & Webster, Inc., Boston, Mass.
Loughridge, C. H., (Member), Consulting Engineer, Cleveland, Ohio
Manahan, W. T., Consolidated Gas, Elec. Lt. & Pr. Co. of Baltimore, Baltimore, Md.
Marsten, J., Freed-Eisemann Radio Corp., Brooklyn, N. Y.
Marthakis, G. S., General Electric Co., Schenectady, N. Y.
Martyn, C. A., Puget Sound Power & Light Co., Tacoma, Wash.
Mason, H. R., Ohio State University, Columbus, Ohio
McBride, B. V., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
McCuaig, D. A., Stone & Webster, Inc., Boston, Mass.
McNichall, J. F., Gould Storage Battery Co., Depew, N. Y.
Means, L. H., General Electric Co., Schenectady, N. Y.
Merritt, D. F., Famous Players Lasky Co., Hollywood, Calif.
Merry, F. S., Toronto Hydro-Electric System, Toronto, Ont., Can.
Metcalf, J. I., Day & Zimmermann, Inc., Philadelphia, Pa.
Monroe, J. J., Westinghouse Elec. & Mfg. Co., Philadelphia, Pa.
Moore, H. A., (Member), U. S. Smelting, Refining & Mining Co., Logan, Utah
Moore, S. A., Holeproof Hosiery Co., Milwaukee, Wis.
Mueller, W. H., Pacific Tel. & Tel. Co., Seattle, Wash.
Muir, W. L., Puget Sound Power & Light Co., Olympia, Wash.
Murch, J. C., General Electric Co., Erie, Pa.
Neighbors, G. F., General Electric Co., Schenectady, N. Y.
Offutt, H. V., Asst. Vice-Pres., First National Bank; Kentucky Title Co., Louisville, Ky.
Osthoff, L. H., The Pacific Tel. & Tel. Co., Seattle, Wash.
Paradis, A., The Pacific Tel. & Tel. Co., Seattle, Wash.
Peck, F. M., Northern Ohio Power & Light Co., Akron, Ohio
Peck, J. L., General Electric Co., Erie, Pa.
Perks, J. A., Philadelphia Electric Co., Philadelphia, Pa.
Perry, R. T., General Electric Co., Schenectady, N. Y.
Pfeifer, W. A., (Member), Tri-State College, Angola, Ind.
Phipps, P., Toronto Hydro-Electric System, Toronto, Ont., Can.
Pixton, W. G., General Electric Co., Schenectady, N. Y.
Piza, J. G., General Electric Co., Schenectady, N. Y.
Quallins, G. A., 237 W. 70th St., New York, N. Y.
Rasmussen, D., Duquesne Light Co., Pittsburgh, Pa.
Reading, A. L., (Member), West Kootenay Pr. & Lt. Co., Substation Trail, B. C.
Reed, R. B., Philadelphia Electric Co., Philadelphia, Pa.
Reid, A., Canadian Crocker-Wheeler Co., Ltd., St. Catharines, Ont., Can.
Richardson, T. P., Jr., A. A. Merrick Engineering Service, Tryon, N. C.
Robinson, G. W., General Electric Co., Schenectady, N. Y.
Robinson, R. B., Philadelphia Co., Pittsburgh, Pa.
Roth, J. D., General Electric Co., Schenectady, N. Y.
Roudebush, G. H., Ohio Bell Telephone Co., Cleveland, Ohio
Samson, R., Puget Sound Power & Light Co., Bellingham, Wash.
Sattenstein, S. L., Bethlehem Steel Co., Bethlehem, Pa.
Schlegel, R. D., Potomac Electric Power Co., Washington, D. C.
Schifreen, C. S., Philadelphia Electric Co., Philadelphia, Pa.
Schreiber, E. H., The Pacific Tel. & Tel. Co., Seattle, Wash.
Schroeder, J. P., Pacific Gas & Electric Co., San Francisco, Calif.
Shallenberger, D. K., Beechbottom Power Co., Power, West Va.
Sharrock, L. L., St. Lawrence County Utilities, Inc., Potsdam, N. Y.
Shaw, J. L., Bethlehem Steel Co., Lackawanna, N. Y.
Sherer, C. M., Pennsylvania Water & Power Co., Holtwood, Pa. (Applicant for re-election.)
Skinner, R. W., Louisville Gas & Electric Co., Louisville, Ky.
Smith, C. E., (Member), J. Livingston & Co., New York, N. Y

Smith, P. C., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Smith, T. T., Puget Sound Power & Light Co., Seattle, Wash.
Snyder, J. N., Duquesne Light Co., Pittsburgh, Pa.
Spaulding, L. S., Electrician-Draftsman, Hazleton, Pa.
Spear, H. E., Puget Sound Power & Light Co., Tacoma, Wash.
Stacy, R. P., Duquesne Light Co., Pittsburgh, Pa.
Steel, E. T., Puget Sound Power & Light Co., Bremerton, Wash.
Steel, F. K., (Member), Great Northern Railway, Seattle, Wash.
Steinmetz, W. C., The Alaskan Railroad, Anchorage, Alaska
Stephenson, J., (Member), Hamilton By-Product Coke Ovens, Ltd., Hamilton, Ont., Can.
Storms, C. A., General Electric Co., Schenectady, N. Y.
Sumner, M. R., Philadelphia Co., Pittsburgh, Pa.
Sylvester, F. E., Great Western Power Co., Oakland, Calif.
Tennant, R. J. J., Duquesne Light Co., Pittsburgh, Pa.
Thedniga, H. H., Manufacturer's Agent, Seattle, Wash.
Thompson, L. A., Puget Sound Power & Light Co., Seattle, Wash.
Thomson, S. E., (Member), Hydro-Electric Power Commission, Niagara Falls, Ont., Can.
Tucker, J. R., Southern Pacific Co., San Francisco, Calif.
Uhlrig, H. W., General Electric Co., Schenectady, N. Y.
Van Huysen, J. W., Garland Affolter Engineering Corp., Seattle, Wash.
Vonsovich, L. J., 2207 Ellsworth St., Berkeley, Calif.
Walker, A. J., Wireless Specialty Apparatus Co., Jamaica Plain, Mass.
Walsh, F., Puget Sound Power & Light Co., Everett, Wash.
Walther, G. J., General Electric Co., Schenectady, N. Y.
Warren, P. L., Ohio Brass Co., Chicago, Ill.
Weckel, G. H., General Electric Co., Schenectady, N. Y.
Wells, D. V., Northwestern Light & Power Co., Sibley, Iowa
Wells, J. P., Century Electric Co., St. Louis, Mo.
White, E. L., Puget Sound Power & Light Co., Seattle, Wash.
Whiteman, W. A., Monongahela West Penn Public Service Co., Wellsburg, West Va.
Williamson, W. S., Prudential Insurance Co., Newark, N. J.
Willits, R. F., Public Service Electric & Gas Co., Camden, N. J.
Woodhouse, G. E., Hydro-Electric Power Commission, Toronto, Ont., Can. (Applicant for re-election.)
Wright, R. B., Puget Sound Power & Light Co., Seattle, Wash.
Yoder, N. W., Leeds & Northrup Co., Philadelphia, Pa.
Zierdt, C. H., Union Switch & Signal Co., Swissvale, Pa.
Total 204

Foreign

Cottier, J. P., Ohakune Borough Council, Ohakune, N. Z.
Dejong, F., Riejos of Puerza del Ebro, S. A., Barcelona, Spain
Della Riccia, A., (Member), Consulting Elec. Engineer, Brussels, Belgium
Kale, P. B., The Central Provinces Engineering Co. Ltd., Nagpur, India
Kothawala, K. R., Elec. Engr., Kishangash State, Kishangash, Rajputana, India
Lapiroff-Scoblo, M., (Fellow), Electrotechnical Inst., Moscow, Russia
Melsom, S. W., (Fellow), Callendars Cable Co., Belvidere, Kent, Eng.
Mori, H., Dept. of Communication, Bureau of Electricity, Tokio, Japan
Parker, W. A. H., West Gloucester Power Co., Ltd., Gloucester, Eng.
Santa-Maria, D., Engr. of Direction, de Servicios Electricos, Santiago, Chile, S. A.
Total 10.

STUDENTS ENROLLED

Angus, William M., Univ. of Toronto
Anspach, Russell J., Ohio Northern Univ.
Barry, Joseph F., Cornell Univ.
Bates, John A., Jr., Cornell Univ.
Blore, Stephen W., Univ. of Idaho
Brolin, Walter B., Northeastern Univ.
Burgan, Kenneth E., Municipal Univ. of Akron
Burnham, Robert F., Univ. of New Hampshire
Byerlay, Henry L., Detroit Inst. of Tech.
Caveny, Charles C., Univ. of Pittsburgh
Churchill, Paul K., Univ. of Southern California
Clark, James V., Denison Univ.
Conard, William, N. Y. Univ.
Cook, Harry W., State Univ. of Iowa
Copeland, Luther W., Georgia School of Technology
Crocker, George E., Calif. Inst. of Tech.
Cross, Rosamond D., Georgia Tech.
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Cleveland	Chester L. Dows	J. F. Schnable, 3503 Mapledale Ave., Cleveland, Ohio
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Washington, D. C.	A. F. E. Horn	L. E. Reed, Potomac Elec. Pr. Co., 14th & C Sts., N. W., Washington, D. C.
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Brooklyn Polytechnic Institute, Brooklyn, N. Y.	J. C. Arnell	J. H. Diercks	Robin Beach
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Clemson Agricultural College, Clemson College, S. C.	B. V. Martin	W. H. Sudlow	S. R. Rhodes
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Cooper Union, New York, N. Y.	F. H. Miller	H. T. Wilhelm	Norman L. Towle
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Yale University, New Haven, Conn.	S. A. Tucker	G. C. Bailey	Charles F. Scott

Total 87

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies

Watthour Meters.—Bulletin 71, 100 pp., entitled "Instructions for Sangamo D-5 Watthour Meters." Sangamo Electric Company, Springfield, Ill.

Tachometers.—Catalog 1700, 24 pp. Describes tachometers for recording and indicating purposes, applicable on all revolving machinery. The Bristol Company, Waterbury, Conn.

Motors.—Bulletin 323. Describes "Master" motors, consisting of a complete line of small motors to fit practically any current specifications. The Master Electric Company, Linden & Master Avenues, Dayton, Ohio.

Bus Connectors.—Catalog 26, 48 pp. Describes a unique line of high tension bus connectors. These devices are for connecting copper tubing and cable in all combinations. Many novel designs are included. Burndy Engineering Company, Inc., 10 East 43rd Street, New York.

Pyrometers.—Catalog 15, 80 pp. In addition to a comprehensive outline of the development of pyrometry, a chapter is devoted to the advantages of pyrometers for various industries and the economies effected. The Brown Instrument Company, Wayne & Windrim Streets, Philadelphia, Pa.

Welding Rods.—Bulletin, 24 pp., "Effect of Surface Materials on Steel Welding Rods." Includes a new arrangement of data on gas and electric filler rod, which shows by means of tables and specifications, uses and the comparative properties of the various types. Chicago Steel & Wire Company, 103rd Street & Torrence Ave., Chicago, Ill.

Oil Engines.—Catalog, 33 pp. Describes direct-injection oil engines for all purposes. The text matter, which consists of technical data and details of the "PO" oil engines of 55, 110 and 150 B. H. P. sizes, is profusely illustrated by forty-two illustrations of plant layouts, installation views, diagrams and engine details. Ingersoll-Rand Company, 11 Broadway, New York.

NOTES OF THE INDUSTRY

Ohio Brass Company Moves Chicago Office.—Announcement is made of the removal of the Chicago office of the Ohio Brass Company from 1217 to 1714 Fisher Building.

W. H. Perkins, who formerly represented the Trumbull Steel Company in the New England territory, is back again after a year's absence and in charge of their Boston Office at 141 Milk Street.

Packard Electric Company, Warren, O., announces the appointment of Harris & Butler, Real Estate Building, Philadelphia, as district managers for Packard transformers in the Philadelphia territory.

H. G. Pierce was made manager of the Berlin office of the International General Electric Company, succeeding L. A. Trone. Mr. Pierce has been with the International Company since 1917, when he had charge of sales in China.

Railway & Industrial Engineering Company, Greensburg, Pa., has purchased the property and building of the Penn Aluminum Company, adjoining their present plant. The building will be enlarged for additional storage space.

New Office for Delta-Star.—H. W. Young, president of the Delta-Star Electric Company, announces the opening of a new and larger office at 140 Cedar Street, New York, in charge of W. S. Nichols, assisted by P. H. Butler and A. R. Beger.

Personnel Changes in Timken Company.—T. F. Rose, formerly assistant manager of the Chicago branch of the Timken Roller Bearing Service & Sales Company, has been appointed branch manager of the Cincinnati office. H. C. Sauer has been appointed manager of the Detroit branch. Mr. Sauer was formerly assistant manager of the Cleveland branch. Fred G. Rumball, formerly branch manager of the Kansas City branch, has been promoted to the position of sales engineer, automotive division, of the Timken Roller Bearing Company. Mr. Rumball will have his headquarters at Cleveland with Edgeley W. Austin, assistant manager of sales. The position of branch manager at Kansas City will be filled by J. M. Carey, who has been promoted from the position of salesman under Mr. Rumball.

New A-C Starter.—A new starter is announced by the General Electric Company, Schenectady, N. Y., bearing the type designation CR-7055-A-1. It is a reversing primary resistor for squirrel cage induction motors. Two three-pole line contactors are provided with this starter. These contactors are electrically and mechanically interlocked and are mounted back-to-back on the panel. A magnetic time interlock provides a predetermined definite time of from one to three seconds between the closing of the line contactor and of the accelerating contactor. Two-point starting is provided by a resistor designed to conform to Electric Power Club classification No. 16. A temperature overload relay with an external resetting mechanism furnishes overload protection. The enclosing case is of sheet metal, semi-ventilated, and is provided with feet for wall mounting.

Synchronous Motor Control.—A complete self-contained, oil-immersed automatic starter for 2300 volt synchronous motors has been developed by the Electric Controller & Manufacturing Company, Cleveland, O. This is built for across-the-line starting of slow speed motors and for reduced voltage starting of the higher speed motors. To start, a button is pushed, and as the motor approaches synchronous speed the field excitation is automatically applied. The reduced voltage starter consists of a welded boiler plate tank which contains an automatic double-throw switching mechanism, a power transformer for providing starting voltage, potential transformers for providing 220 volts for the master switch operating current and the current limit transition relay, which connects the motor to full voltage when it has been accelerated to approximately 85 per cent of synchronous speed. The equipment is complete in a single unit, which makes possible floor mounting of all the apparatus necessary for starting synchronous motors.

Building Program of $5,000,000 For Westinghouse.—The present building program for the expansion of facilities at various plants and offices of the Westinghouse Electric & Manufacturing Company will involve an expenditure of $5,525,000, according to T. P. Gaylord, acting vice-president of the company. The cost of the general office building now nearing completion at the Pittsburgh Works is $1,500,000. Additional construction is under way or will begin soon on the company's plants at Mansfield, Detroit, St. Louis, Springfield, Sharon and Derry.

Pyrex for High-Voltage Insulators.—The Corning Glass Works, Corning, N. Y., announces its entrance into the electrical transmission field with high-tension Pyrex insulators. The company states that many years of intensive research has proven that Pyrex insulators have the required qualities necessary for a perfect insulator. These qualities are said to be low temperature rise with uniform temperature throughout, transparency permitting ease of inspection, non-hygroscopic, permanent and uniform dielectric strength, quick drying surface, and the ability to withstand concentrated power arcs. Several thousands of these insulators are said to have been in service on the Montana Power system for about two years. At the present time the company is offering pin-type insulators of a one-piece design for operating voltages from 6,600 to 50,000. Development work is proceeding on suspension and flange or stack-type units and further announcements regarding these will be made later. Raymond W. Lillie is Manager of Power Line Insulator Sales, located at Corning Glass Works, 501 Fifth Ave., New York City. The main factory and offices are located at Corning, N. Y.


The careful investor judges a security by the history of its performance.
KERITE
in a half-century of continuous production, has spun out a record of performance that is unequalled in the history of insulated wires and cables.
Kerite is a seasoned security.
DAYS KERITE
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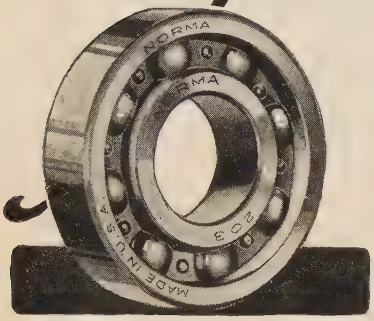
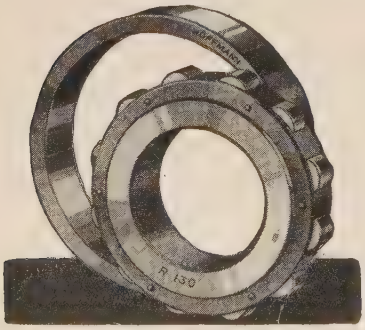
COMPANY INC

Why Should the Life and the Earning Power of an Electric Motor be Limited by its Bearings?



"NORMA"
PRECISION
BALL BEARINGS

and
"HOFFMANN"
PRECISION
ROLLER BEARINGS



MAKE
GOOD MOTORS
BETTER

Motor windings seldom fail. Good insulations stand up. Commutators wear but slowly. Brushes are easily and inexpensively replaced.

What, then, makes motors "wear out"? What cuts down their efficiency and finally fails?

Experience, alike of motor manufacturer and motor user, furnishes the answer—**inadequate, unreliable, sleeve type bearings.**

Whatever of anti-friction quality a sleeve type bearing possesses, it has by virtue of the lubricant used and not because of any friction-reducing quality in the sleeve type bearing itself.

The success or failure of such a bearing, then, depends upon its lubrication. Inadequate, or neglected, or improper lubrication means the failure of the sleeve type bearing—and this means the failure of the motor.

The one and only complete solution of the motor bearings problem lies in the use of true anti-friction bearings—

Bearings which, though vastly improved in their operation by ample and proper lubrication, are yet not absolutely dependent upon the lubricant for their anti-friction qualities—

Bearings designed to provide, in their mountings, a store of lubricant ample for long periods of high-efficiency operation, without renewal or attention—

Ball Bearings for motors of smaller powers and higher speeds: **Roller Bearings** for motors of larger powers and heavier duty.

The production cost, to the manufacturer, and the purchase price, to the buyer, may be a little higher for the ball or roller bearing motor.

But this difference is far over-shadowed by the subsequent savings resulting—the saving in lubricant, the saving in current, the uninterrupted service, the lower up-keep, the longer life of sustained high efficiency.

NORMA-HOFFMANN BEARINGS CORPORATION
Stamford – Connecticut
PRECISION BALL, ROLLER AND THRUST BEARINGS

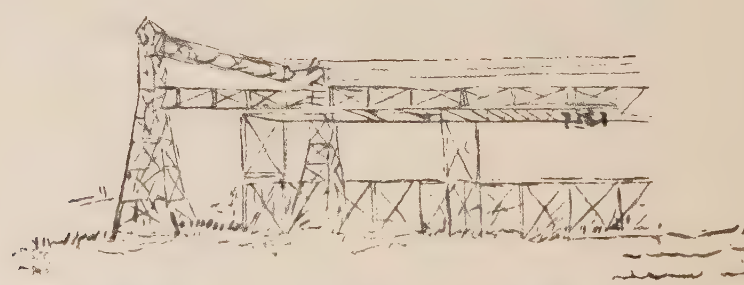
Out where trouble may begin

The black spot marks where trouble is the most likely to begin—out on the distribution line.

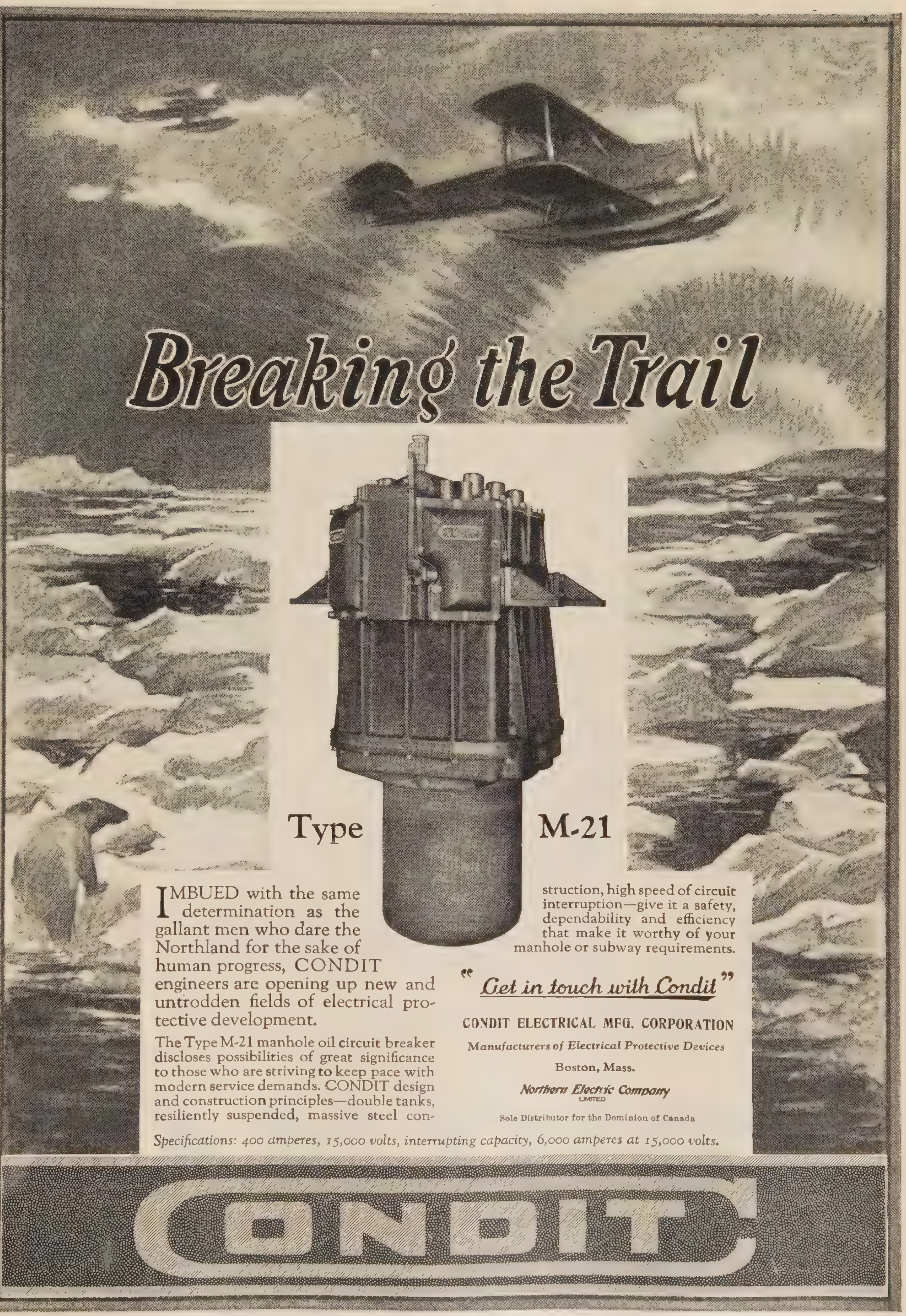
Failure of equipment to clear the line without danger to itself, allowing the trouble to spread, means an interruption—a "black spot" on your service.

Therefore, stop line trouble near its source; stop it at the outlying substation—in the explosion chamber of a General Electric oil circuit breaker.

The success of G-E Oil Circuit Breakers reflects the value of the experimental work done by a large organization at a cost of millions annually. Only by means of the experimental and testing facilities at the disposal of G-E engineers could G-E switching devices and complete equipment have been perfected as they are today. This applies also to other apparatus for control, protection and distribution, all of which can be furnished by General Electric.



GENERAL


Breaking the Trail
Type M-21
IMBUED with the same determination as the gallant men who dare the Northland for the sake of human progress, CONDIT engineers are opening up new and untrodden fields of electrical protective development.
The Type M-21 manhole oil circuit breaker discloses possibilities of great significance to those who are striving to keep pace with modern service demands. CONDIT design and construction principles—double tanks, resiliently suspended, massive steel construction, high speed of circuit interruption—give it a safety, dependability and efficiency that make it worthy of your manhole or subway requirements.
"Get in touch with Condit"
CONDIT ELECTRICAL MFG. CORPORATION
Manufacturers of Electrical Protective Devices
Boston, Mass.
Northern Electric Company Limited
Sole Distributor for the Dominion of Canada
Specifications: 400 amperes, 15,000 volts, interrupting capacity, 6,000 amperes at 15,000 volts.
CONDIT

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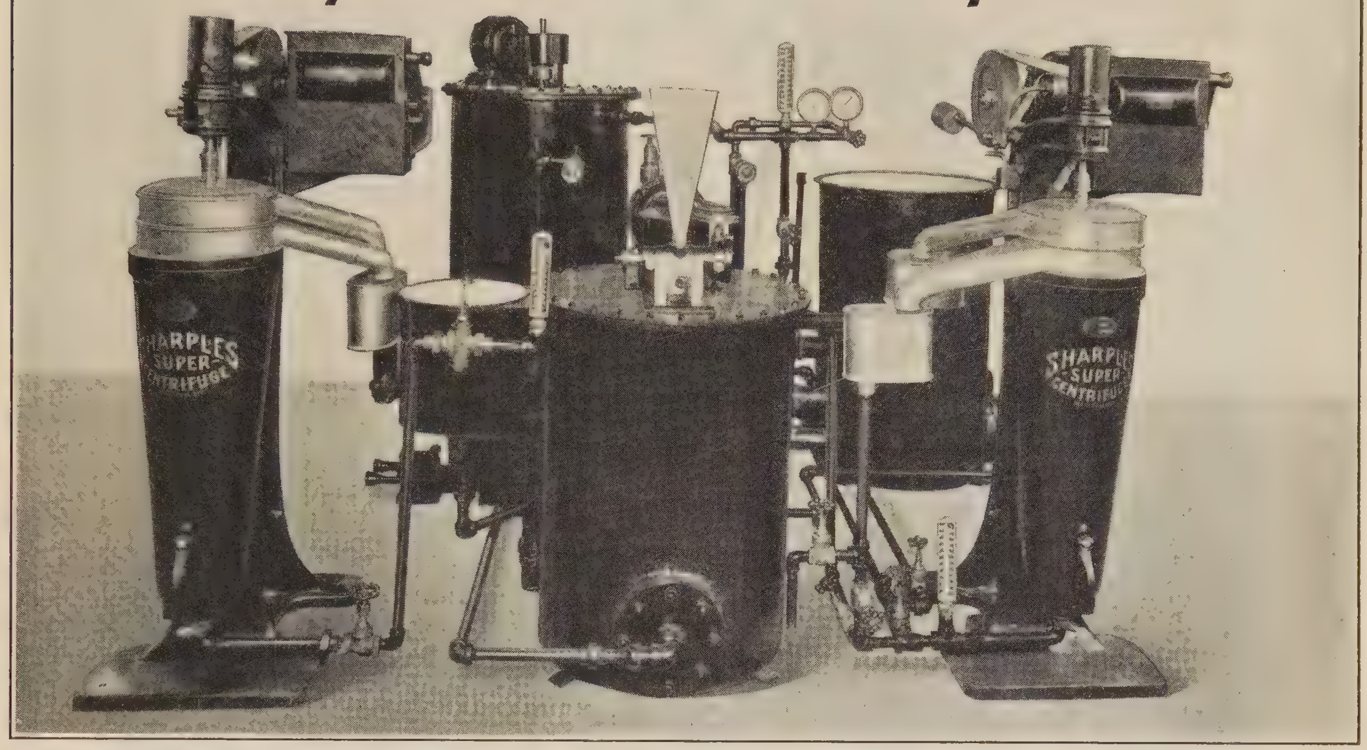
The last word in Switch and Transformer Oil Purification



SHARPLES PROCESS
for Purification of Used Insulating Oils

Of the many centrifugal processes Sharples has contributed to various industries, one of the most important is the Sharples Chemical-Centrifugal Process for reconditioning switch oils, which is a real contribution to the electrical industry.

The Sharples Process illustrated above can be used for the chemical-centrifugal treatment of not only badly carbonized switch oils, but also for sludged transformer oils.

Each of these centrifugal machines can also be used independently for the dehydration of transformer oils when not in use in the chemical-centrifugal process.

For the first time it is now possible to recondition insulating oils that previously had to be discarded.

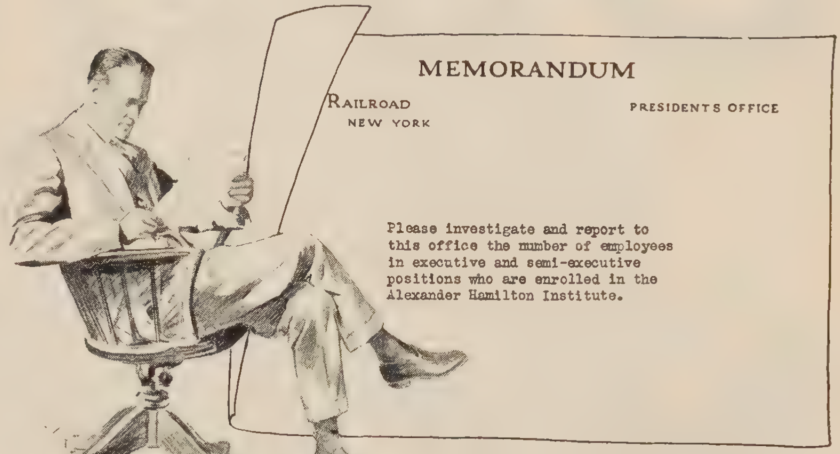
The cost of reconditioning such oil is so low that large users of circuit breaker oils can realize a splendid return on their investment in this process.

Sharples Engineers will forward complete details on this process to all interested parties. Write today for these important facts.

THE SHARPLES SPECIALTY COMPANY, 2324 WESTMORELAND STREET, PHILADELPHIA. Boston, New York, Pittsburgh, Chicago, Detroit, Tulsa, New Orleans, San Francisco, Los Angeles, Seattle, London, Paris, Tokio.

SHARPLES
A GREAT FORCE

—*and he thought no one was watching him!*



This inquiry was sent to all departments from the executive offices of one of America's largest railroads

HE is a junior executive in a western office of one of the largest railroads. It seemed a very long way from his desk to the president's—hard to believe that any one in New York was watching him, or caring particularly what plans he made for his future.

One day came the memorandum which is quoted in substance at the right. It was a distinct surprise to the young executive; he thought about it after he reached home that evening. The next morning he sent a letter to the Alexander Hamilton Institute.

> "If the Company thinks your Course is a good thing for us and makes personal inquiries as to whether we are enrolled or not, it is time for us to sit up and show some interest in ourselves," he wrote.

There is a double significance in this incident. It is of interest first

To you, Mr. President

Do you know how many men in your organization are taking the Alexander Hamilton Institute Course? More and more big corporations are asking this question. In the Standard Oil Company, for example, 1,447 men are enrolled; in the United States Steel Corporation, 698 men; in the General Electric Company, 979 men. And among these numbers are included the names of the most important officials, as well as those of younger men who are on the way to executive positions.

If the biggest businesses in the country feel the supreme importance of executive training for their men, doesn't *your* business have the same necessity? Isn't it worth your while at least to get the facts about this Course which has grown steadily in favor with business leaders for fifteen years?

To you who are not a President

You are, let us say, between twenty-five and forty. You are on your way up. Perhaps you are in a big enterprise, and it seems sometimes as tho the men at the top were hardly conscious of your existence. Or perhaps the company is small, and the possibilities apparently limited. You wonder sometimes whether your hard work is really getting you anywhere. Is anyone watching you? Is there anything you can do to give yourself an advantage which other men do not have?

You can be sure of one thing—*there is a search for all-round executives in this country, which grows more and more keen every year.* There are department heads aplenty—men who know selling, men who know accounting, men who know advertising, or office management, or commercial law. But the men who know the fundamentals of *all* these are very few and the demand for them is insistent.

Send for this definite plan

The Alexander Hamilton Institute gives to men the equipment which modern business seeks most and for which the largest rewards are paid. It trains men to direct men; to understand the working of all departments—to analyze and decide.

Only a training which is authoritative and practical could have the endorsement of the men who constitute the Advisory Council of the Alexander Hamilton Institute.

They are:

T. Coleman duPont, the well-known business executive; Percy H. Johnston, President of the Chemical National Bank of New York; Dexter S. Kimball, Dean, College of Engineering, Cornell University; John Hays Hammond, the eminent consulting engineer; Frederick H. Hurdman, Certified Public Accountant and business advisor; Dr. Jeremiah W. Jenks, the statistician and economist.

There is no mystery about the Institute. The whole story is down in a booklet entitled "Forging Ahead in Business."

We invite you to send for this book. Send whether you are a president, or a future executive. The book is sent without cost or obligation, and our desire is to have a copy in the hands of *every* mature and thoughtful business man.

This coupon will bring you the facts

ALEXANDER HAMILTON INSTITUTE
600 Astor Place New York City

Send me the book, "Forging Ahead in Business," which I may keep without obligation.

Name..
Please write plainly

Business Address ....

....

Business Position..

Alexander Hamilton Institute

In Canada: C. P. R. Building, Toronto *In Australia: 11c Castlereagh St., Sydney*

DUDLO

MAGNET WIRE AND WINDINGS

Volume

Makes it possible for this plant to supply manufacturers of electrical apparatus unequalled products and service in

Fine Magnet Wire and Coils For Every Purpose

This has become such a *highly specialized* field that even the largest electrical manufacturers in the country are now using DUDLO Wire and Coils instead of attempting to make their own. They find *it pays from every standpoint.*

Automobile manufacturers, whether large or small, have found that it does not pay them to try to make such parts as spark plugs or tires. These are special lines of manufacture. For the same reason, manufacturers of electrical apparatus do not attempt to produce their own coils or windings, but find their greatest success results from concentration on their own products.

Manufacturers are invited to make our experimental laboratories a department of their own business. We suggest you allow our engineers to develop coils for your products. No obligation. Estimates will be gladly furnished on coils built to your specifications.

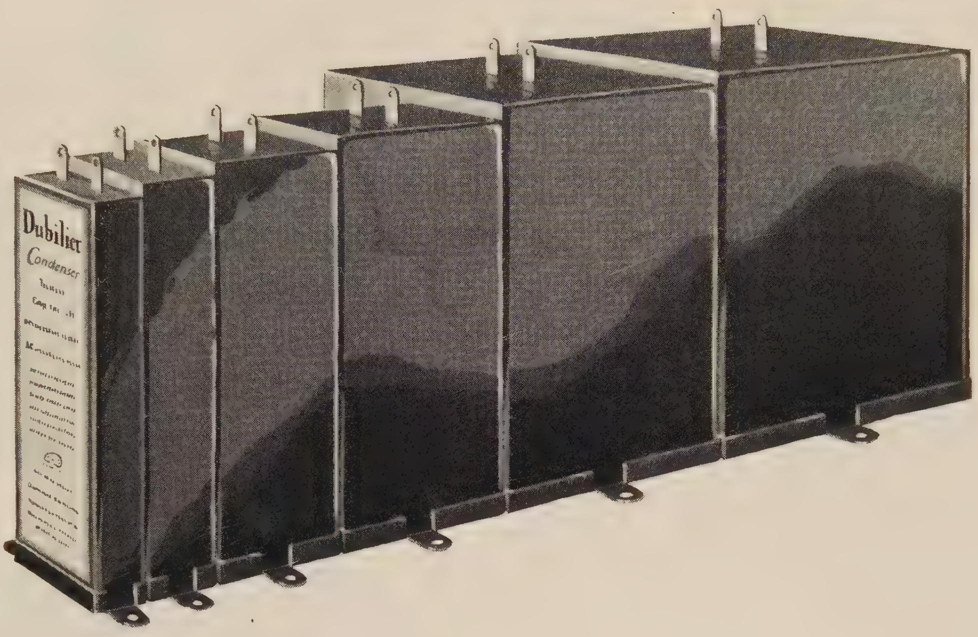
This illustration pictures a small section of the great DUDLO plants at Fort Wayne, Indiana, the world's largest factories devoted exclusively to quality Coils and Magnet Wire

Eastern Office and Warehouse
412 Chamber of Commerce Bldg.
NEWARK, N. J.

Chicago Office
160 N. La Salle St.
CHICAGO, ILL.

DUDLO MANUFACTURING CORPORATION FT. WAYNE, IND.

Dubilier paper dielectric industrial condensers



Specify Dubilier condensers for all industrial purposes. Dubilier condensers are giving complete satisfaction in innumerable types of electrical equipment—viz.:

- Sign Flashers
- Magnetoes
- Electro Medical Apparatus
- Telephone and Telegraph Equipment
- Submarine Cables
- Signaling Systems
- Contactors
- Radio
- Power Factor
- Scientific Instruments

and many other kinds of electrical apparatus.

Dubilier engineering facilities are at your serviçe—let us quote on your requirements.

Dubilier

CONDENSER AND RADIO CORPORATION

4377 Bronx Blvd., New York, N. Y.

Transmission Towers

For use where heavy ice occurs frequently

THE illustration shows the heavy ice loading that has occurred in some parts of the country.

The tower shown was designed and tested on its own foundations (earth footings) for this special condition, and it has also proven to work satisfactorily under actual heavy ice.

AMERICAN BRIDGE COMPANY

EMPIRE BUILDING, 71 BROADWAY - NEW YORK, N.Y.

Selling Offices in Principal Cities

Tower Department - Frick Building - Pittsburgh, Pa.

I. P. Morris Hydraulic Turbines

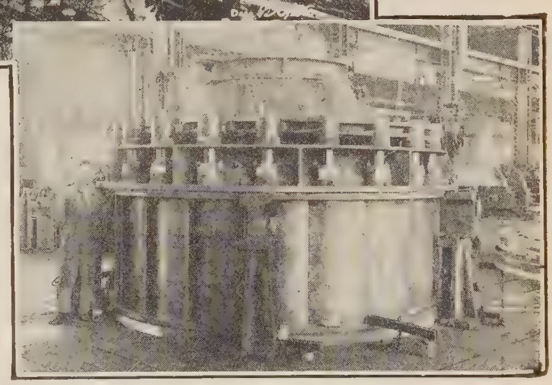
The Wm. Cramp & Sons Ship & Engine Building Co.

Richmond and Norris Sts., Philadelphia

New York Office: 100 Broadway **Birmingham Office: American Trust Building**

Cheat Haven Hydroelectric Station
System of the West Penn Electric Company

Four 18,000 hp. I. P. Morris Turbines are at present being installed for operation under a head of 81.5 ft., at a speed of 133.3 r.p.m.



THE SUB-STRUCTURE of the power station was constructed about thirteen years ago. The draft tubes and scroll cases formed in the concrete of this original construction were designed for turbines of 12,000 H. P. capacity. The Power Company subsequently decided that its load characteristics warranted the installation of larger units and, after a series of experiments conducted in the I. P. Morris Hydraulic Testing Laboratory on several models of turbine runners and various modifications of the original draft tube design, it was found that turbines developing at least 50% more power than those for which the station was originally planned could be installed in the original settings with some modifications thereof. These tests also indicated that such larger turbines, developing 18,000 H. P., could be expected to operate satisfactorily and at high efficiencies with the modifications incorporated in the revised designs of the structures.

This station was designed and is being constructed by Sanderson & Porter, Engineers, New York, in collaboration with Mead & Scheidenhelm, Consulting Engineers, and the engineers of the West Penn System.

Designers and builders of the Johnson Hydraulic Valve and the Moody Spiral Pump

ASSOCIATED COMPANIES

THE PELTON WATER WHEEL CO., San Francisco and New York

DOMINION ENGINEERING WORKS, LTD., Montreal, Canadian Licensees

SOCIEDADE ANONYMA, HILPERT, Rio de Janeiro, Brazilian Licensees

Company— 220,000 Volt Line

THREE SALIENT CHARACTERISTICS OF THE LOCKE GRADING SHIELD.

1- Reduces voltage stress on line unit

2- Increases lightning arcover voltage of insulator string.

3- Prevents damage to insulators and conductor when arcovers occur.

THE LINE IS EQUIPPED THROUGHOUT WITH

① Locke No. 7500 High-Strength Suspension insulators

② Locke Grading Shield Equipments on all Strings

③ Locke Double and Triple Yoke Sets on Multiple Strings

Locke Insulator Corporation, Baltimore, Md.

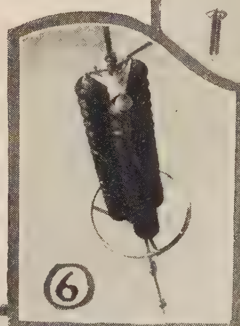
Factories at Victor, N. Y., and Baltimore, Md.

Sales Offices:

Boston, Mass., 84 State St. New York, N. Y., 120 Broadway; Victor, N. Y.; Philadelphia, Pa., 803 Atlantic Bldg.; Dallas, Texas, 1801-15 North Larmar St.; Chicago, Ill., 770 Illinois Merchants Bank Bldg.; Atlanta, Ga., 414 Red Rock Bldg.; Salt Lake City, Utah, 310-314 West Second South St.; Denver, Colo., 819 Seventeenth St.; San Francisco, Cal., 575 Mission St.; Los Angeles, Cal., 236 S. Los Angeles St.; Portland, Oregon, 61 Fifth St. North; Seattle, Wash., 570 First Ave., South.

Export Agents:

International General Elec. Co., Schenectady, N. Y.



VIEWS

⑤-Top of tower shown in view No. 4

⑥-Heavy duty triple yoke set

⑦ Heavy duty suspension and guy construction

PORCELAIN

Preventing a mix-up between plane and power line

In order that aircraft using the Ford Airport near Dearborn, Michigan, would not endanger or be endangered by a 24,000-volt transmission line, a section of the line 700 feet long was put underground. G-E single-conductor armored cable, buried directly in the ground, was installed by the Detroit Edison Company.

The unfailing operation of this cable since it was put in service more than a year ago justifies the confidence placed in it—a confidence that G-E Cables have won all over the world by their consistently uniform high quality that guarantees uninterrupted service.

In service in all corners of the world, G-E Wires and Cables are meeting successfully the most severe operating conditions.

49-8

GENERAL ELECTRIC

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., SALES OFFICES IN ALL PRINCIPAL CITIES

Amazing Security

The quick easy installation of Matthews Scrulix Anchors brings absolute assurance of perfect anchorage under severest conditions of service.

HERE is the scientifically correct, low cost anchoring method that has brought freedom from difficulties common to all pole line anchoring. In all parts of the world where time-saving, trouble-proof installations in every conceivable type of surface are required, these anchors are used. Hundreds of thousands of them throughout the United States are proving themselves practically indispensable through years and years of utterly dependable service.

In 5 to 15 Minutes

In less time than it takes to get a hole well started, two men can turn a Matthews Scrulix Anchor deep down under tons of earth without loosening the ground above. They come completely assembled, all in one piece, ready to install by simply screwing them into place. No moving parts to become lost or buried unadjusted. One of the simplest operations in erection work.

Multiplied Holding Power

The Matthews Scrulix Anchor is so designed that under strain the lines of force radiate from the helix of the anchor at forty-five degree angles. Instead of depending merely upon the column of earth close to the shaft for holding power, it brings into play the tremendous weight of hundreds of cubic feet of earth around it. For all ordinary purposes the use of comparatively small sizes is adequate.

No Creepage

Under water, in hard pan, loam, shale—wherever unusual anchorage problems occur—Matthews Scrulix Anchors demonstrate their advantages. They hold fast—are easy to install. Made in seven different sizes, Matthews Scrulix Anchors present an easy solution for your anchorage problems.

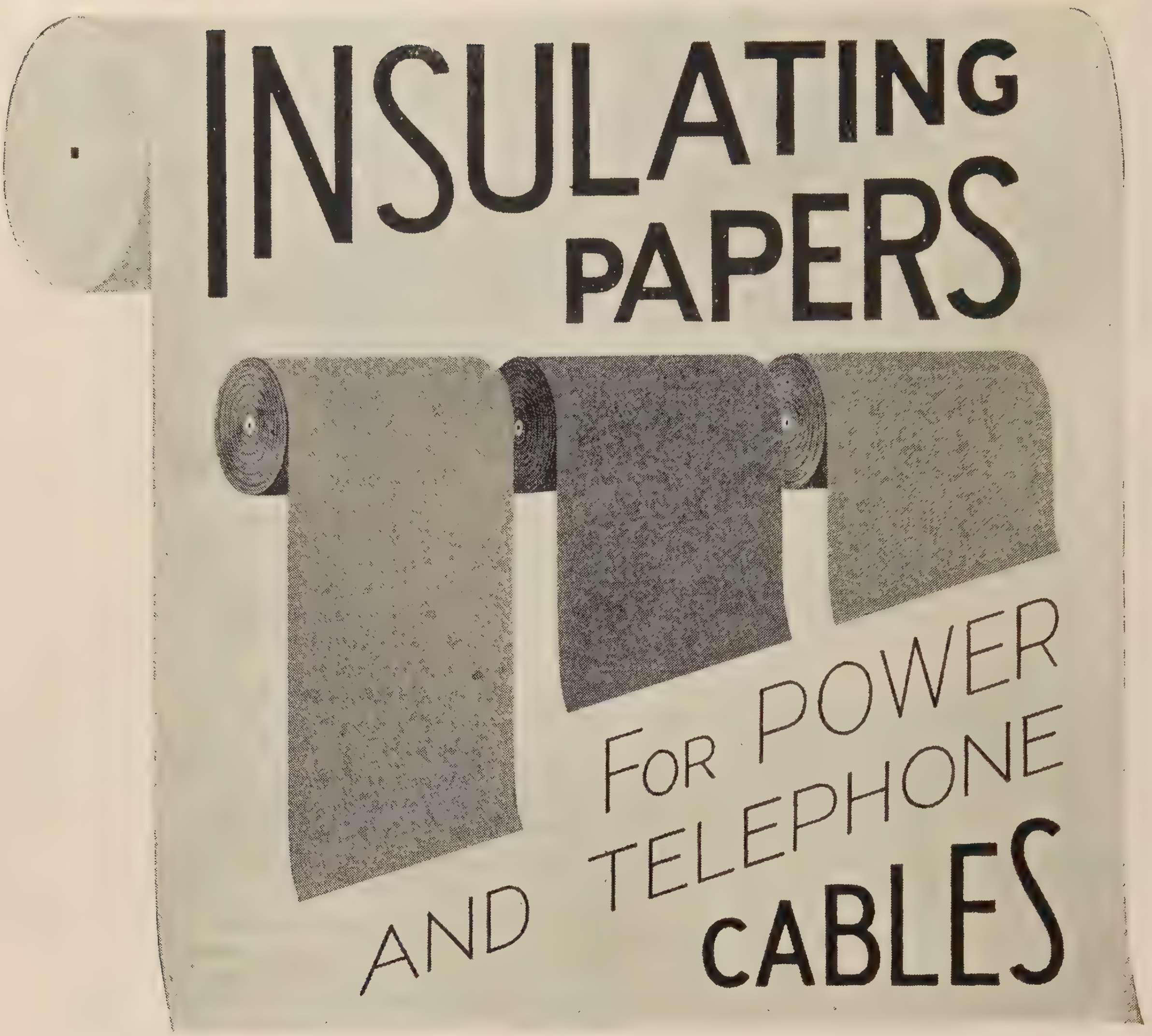
Learn More About Them Now

Write for our Bulletin 800, covering in detail the interesting variety of applications of this anchoring principle. It will reveal to you complete mastery of anchorage problems as met by many companies during the last twenty years.

W. N. MATTHEWS CORPORATION
3706 FOREST PARK BLVD. ST. LOUIS, U.S.A.

Ask about these Matthews Fuswitches · Matthews Disconnecting Switches · Matthews Scrulix Anchors · Matthews Adjustable Reel · Matthews Guy Clamps · Matthews Slack Puller · Matthews Cable Clamps · Matthews Lamp Guards · Matthews Telefault · Matthews Teleheight · *Distributors in all principal cities.*

MATTHEWS
SCRULIX ANCHORS



Trade Mark—"ROTHMILL"

Made under Highly Specialized Technical and Practical Control resulting in the Production of Paper Combining *Greatest Mechanical Strength with Highest Insulating Properties*

by

TULLIS, RUSSELL & CO., LTD.,

PAPER MAKERS

ESTABLISHED 1809

HEAD OFFICE AND MILLS
MARKINCH, SCOTLAND
CABLES—"TULLIS, MARKINCH"

SALES OFFICE
1, TUDOR STREET
LONDON, E. C. 4, ENG.
CABLES: AUCHMUTY, LONDON

MANCHESTER OFFICE
376 CORN EXCHANGE BUILDING
CORPORATION STREET
MANCHESTER

American Steel & Wire Company's

PARK and SUBURBAN CABLES

Tried, Tested and Approved

through actual service—

IT is high recommendation that the industry continues to buy products of the American Steel & Wire Company in ever increasing quantities, with ever increasing confidence in the results.

This confidence is particularly emphasized with American Park and Suburban Cables. Here, where the product cannot be seen in use, purchase is influenced almost entirely by the buyer's confidence in the manufacturer.

You can specify American Steel & Wire Company Park and Suburban Cables with every assurance that the product and the service will be right.

Sales Offices:

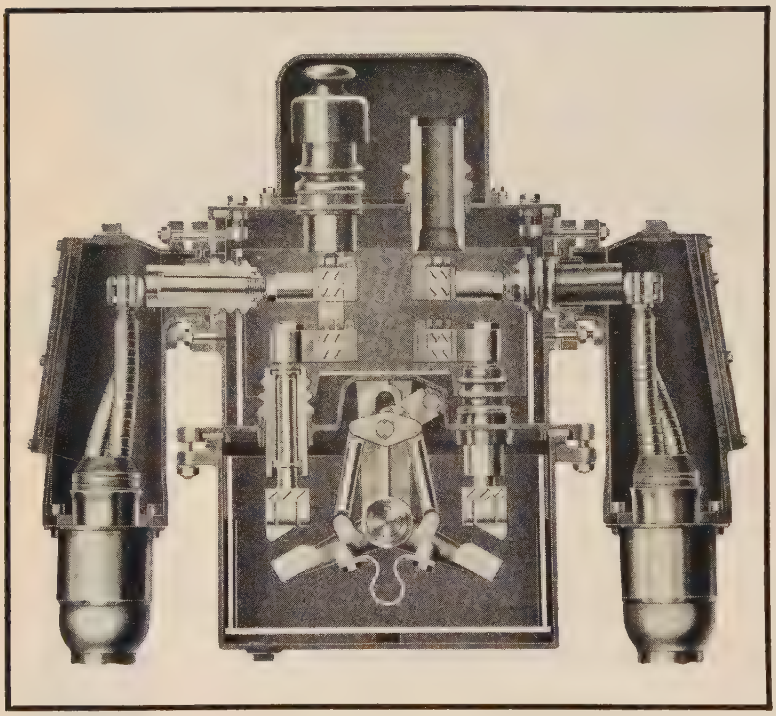
Chicago, New York, Boston, Cleveland, Worcester, Philadelphia, Pittsburgh, Buffalo, Detroit, Cincinnati, Baltimore, St. Louis, Wilkes-Barre, Kansas City, St. Paul, Oklahoma City, Birmingham, Memphis, Dallas, Atlanta, Denver, Salt Lake City

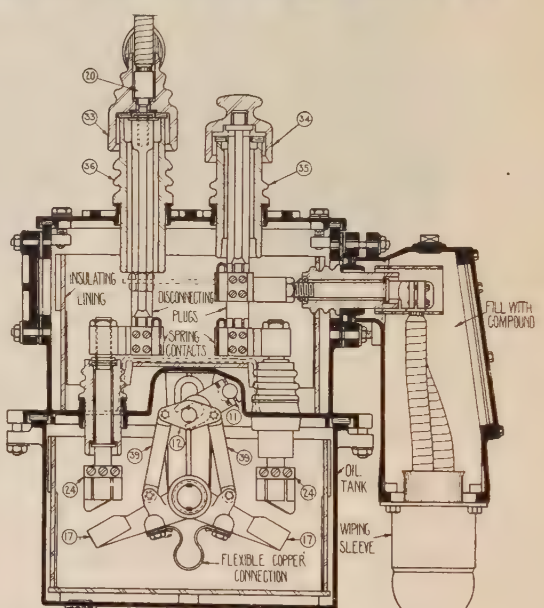
Export Representative: U. S. Steel Products Co., New York

Pacific Coast Representative: U. S. Steel Products Company, San Francisco, Los Angeles, Portland, Seattle

The G&W Oil Disconnect is a Combination Oil Switch and Manual Disconnect, compact, simple in operation and well designed, being completely watertight and can be used in manholes which fill up with water

G&W Oil Disconnects





THE G & W Oil Disconnect meets the ever-growing need of a submersion proof oil disconnect for use with lead cables in manholes or vaults. Remote manual control for operation from street level can be furnished.

Safety and convenience of operation are points well developed. The oil disconnect can be completely isolated from potential for inspection and repairs. Pulling the porcelain caps on top of the unit disconnects the cable from the switch. The iron hood over the porcelain caps is easily removed.

The cable foreman can remove the manual disconnect before repair work is begun and the cable can be handled in safety. Accidental closing of the oil disconnect will cause no damage.

The Oil Disconnect is made on the regular G. & W. Unit Plan Basis

For cable pole use, the external fittings of the G & W Oil Disconnect are rearranged. The overhead system can be connected to the underground thru the G & W Oil Disconnect. The unit can be hung similar to a transformer to a crossarm. You simply pull the porcelain cap and the underground is isolated from the overhead.

For straight overhead work, this unit makes an ideal oil disconnect. Blank side plates are installed at the lead cable openings. Aerial leads are used on both sides at the top of the disconnect.

Ease of Installation

The Oil Disconnect is shipped fully assembled. Installation, because of design, has been made most simple. This Oil Disconnect is listed and fully described in the G & W catalog No. 26. See our nearest representative or write us direct.

G&W ELECTRIC SPECIALTIES

Exactly What You Want!

G & W design and manufacture practically every device for the end of a cable.

Potheads	Underground Boxes
Series Cutouts	Conduit Bells
Primary Cutouts	Ground Pipe Caps
Oil Fuse Cutouts	Ground Pipe Points
Vault Unit	Oil Disconnect

G & W ELECTRIC SPECIALTY CO.
7780 DANTE AVE. CHICAGO, ILL.

Spot the Dosserts

When you see a clean-cut layout such as this 23,000 volt bus at the Acme Station of the Toledo Edison Company—spot the Dosserts.

In any indoor or outdoor station, in any distribution or industrial wiring job where branches are connected to mains, where straightaway or T's or Y's or deadend connections are modern —spot the Dosserts.

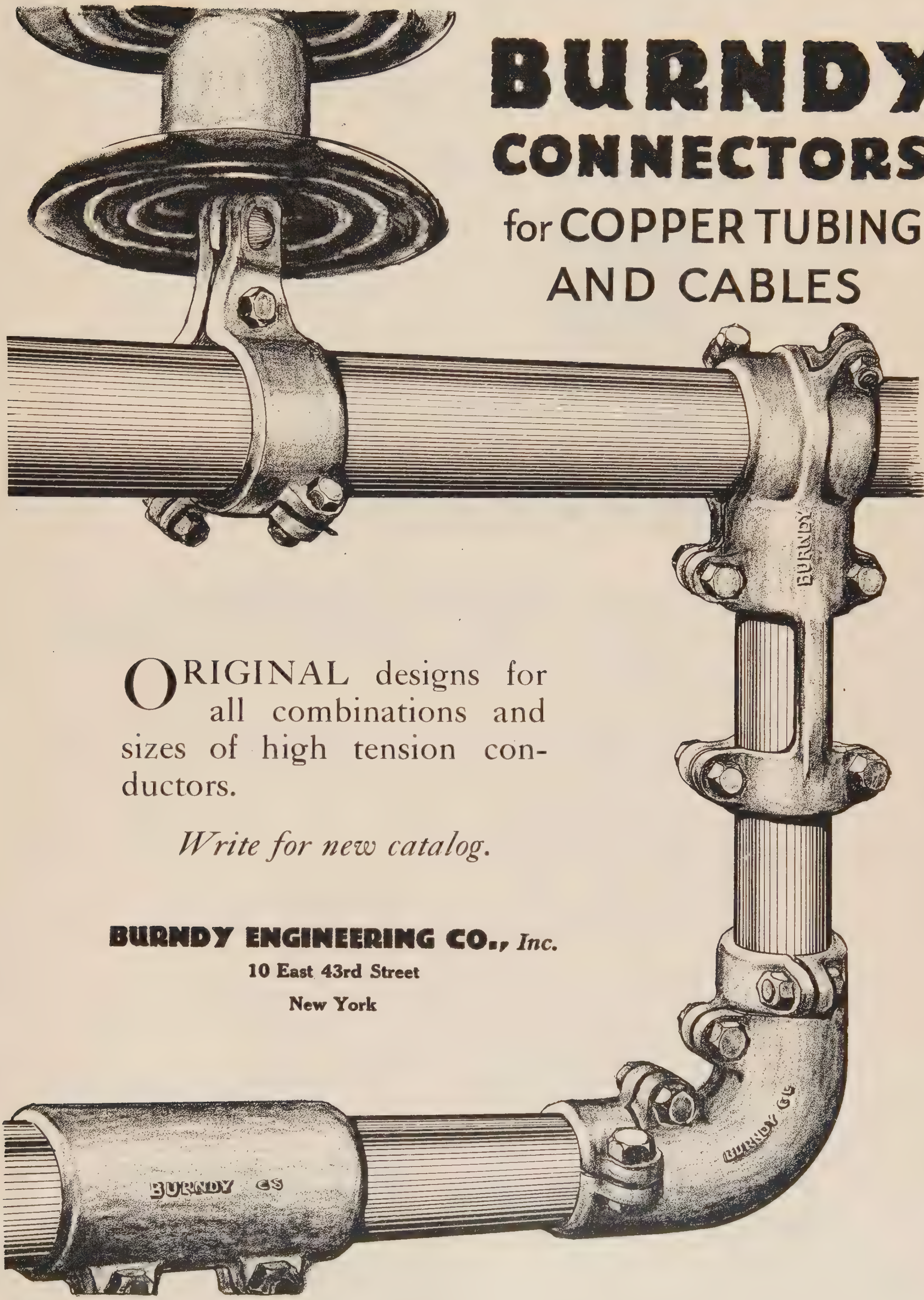
The Dossert 20th Year Book is full of data on efficient connections for wire, cable or rod.

DOSSERT & COMPANY, H. B. Logan, *President,* 242 West 41st St., New York

DOSSERTS

BURNDY CONNECTORS

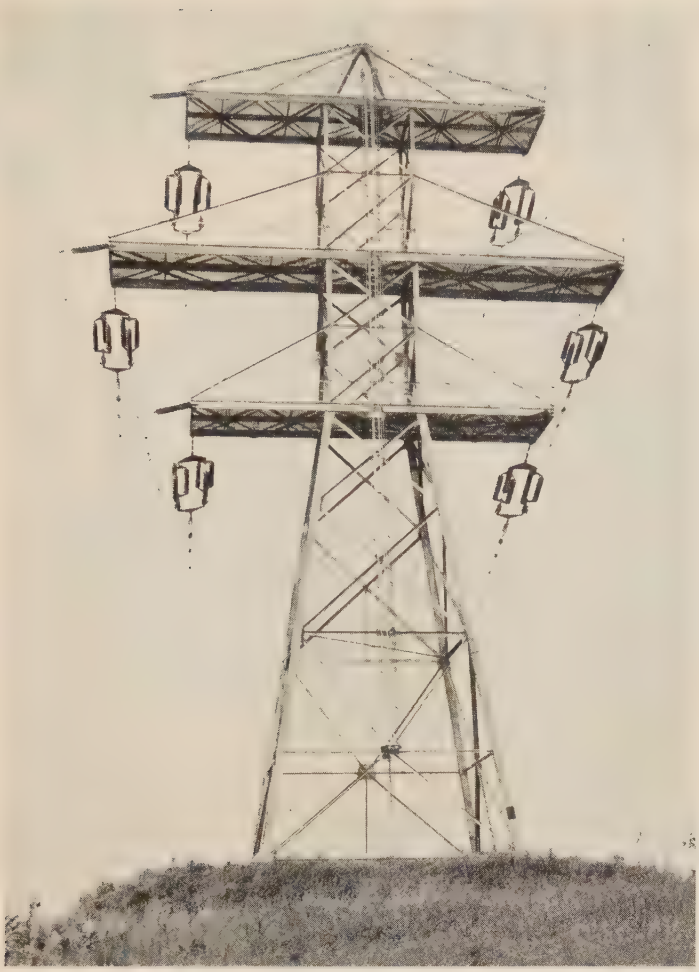
for COPPER TUBING AND CABLES



ORIGINAL designs for all combinations and sizes of high tension conductors.

Write for new catalog.

BURNDY ENGINEERING CO., *Inc.*
10 East 43rd Street
New York



Major Construction on Lapp Insulators

Lapp No. 2094 high strength suspension insulators at 132,000-volts on Mississippi River crossing of Union Elec. Lt. & Pr. Co., St. Louis, Mo.

This crossing is described in the Oct. 1925 JOURNAL *of A. I. E. E.*

Lapp Insulators have been selected for many of the most difficult situations. Thus, Lapp Insulators for —

Eagle Rock-Laguna Bell line of Southern California Edison Co.,—*all anchorages on Lapp Suspension Insulators.*

Illinois Central R. R.—*Chicago electrification on Lapp Insulators.*

Public Service Elec. & Gas Co., Newark, N. J.—132,000-*volts on Lapp Insulators.*

Miss. River crossing of Louisiana Pr. Co., Vicksburg, Miss.—110,000-*volts on Lapp Insulators.*

WJZ at Bound Brook, N. J. and WGY at Schenectady—*towers supported on Lapp Insulators.*

British P. O Dept. radio station, Rugby, England,—*antenna on Lapp Insulators.*

Lapp Insulators do not fail. Lapp Insulators now cost no more than others. Lapp vacuum process porcelain is superior. Lapp Insulators never require replacement, except because of external mechanical breakage.

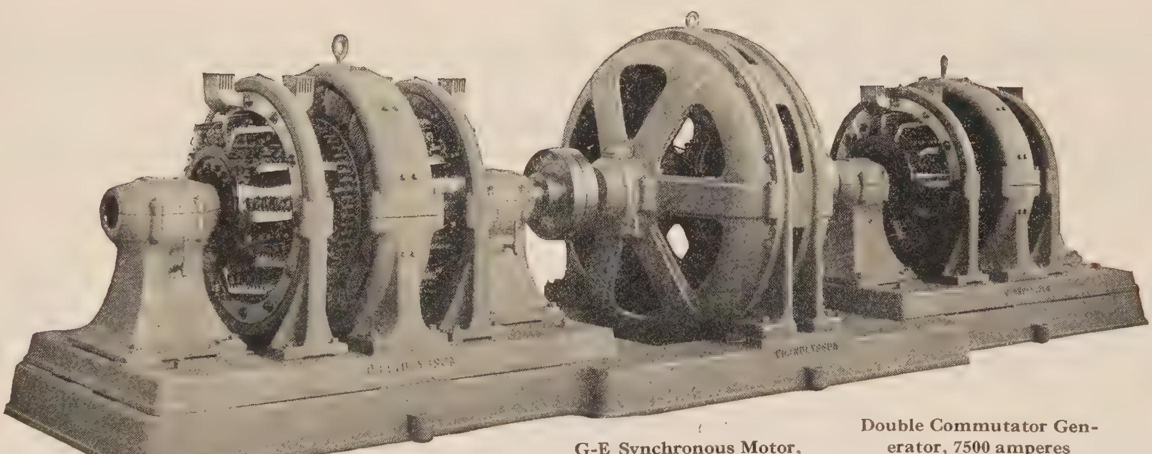
LAPP INSULATOR CO. INC. LE ROY, NEW YORK

Chandeysson

Generators
25 to 25,000 Amperes

Direct Connected to

GE Motors



Double Commutator Generator, 7500 amperes at 8 volts

G-E Synchronous Motor, 200 h. p., 3-phase, 60 cycles 440 volts

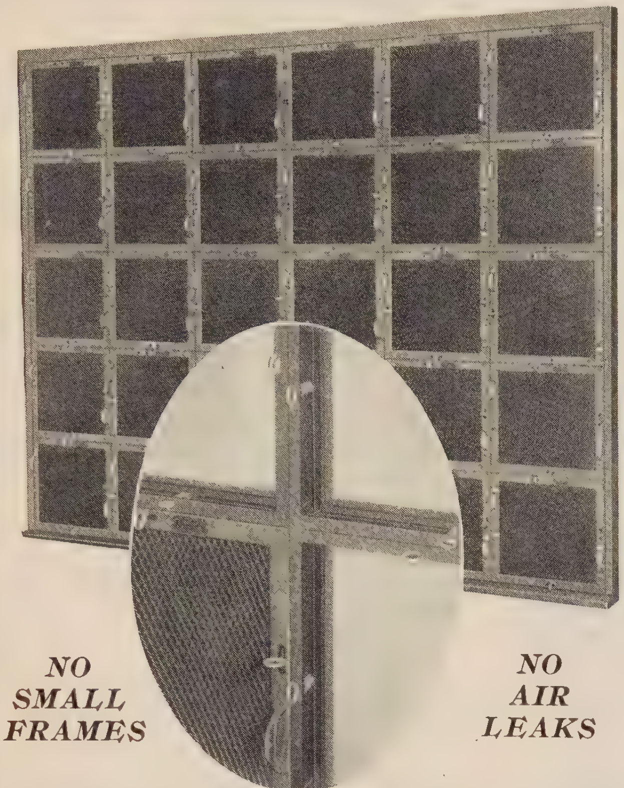
Double Commutator Generator, 7500 amperes at 8 volts

15000-AMPERE
UNIT

OPERATING AT THE RIM GALVANIZING PLANT OF THE

GENERAL MOTORS CORPORATION

Installed in 1922 CHANDEYSSON ELECTRIC CO., ST. LOUIS, U. S. A.



NO SMALL FRAMES

NO AIR LEAKS

SPRACO AIR FILTERS
FOR POWER STATIONS

are particularly well adapted for cleaning the air for electric generators, air compressors, internal combustion engines, and also for switch rooms, substations, etc.

Both the initial and operating cost is low, while maintenance expense is negligible.

SPRACO AIR FILTERS have an exceptionally high cleaning efficiency and are of unusually rugged design and construction. For further particulars send for bulletin F-69.

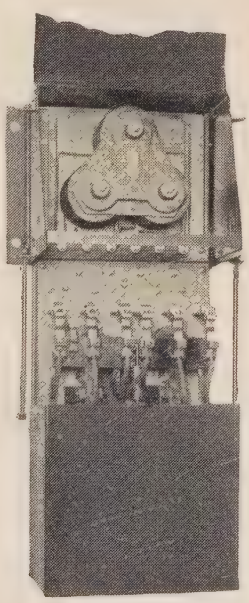
Air Washers
Cooling Ponds
Spray Nozzles

PATS. PEND.

Spray Engineering Company
60 High Street
BOSTON, MASSACHUSETTS

Air Filters
Strainers
Flow Meters

That Year in and Year out Service



ROWAN
Impedance Starter

for

Squirrel Cage Induction Motors

ROWAN CONTROL
THE ROWAN CONTROLLER CO., BALTIMORE, MD.

Turbo generators and Switchboard room protected by Midwest installation (located in housing).

Your Main and Sub-Stations Need Clean Air, Wherever They Are Located

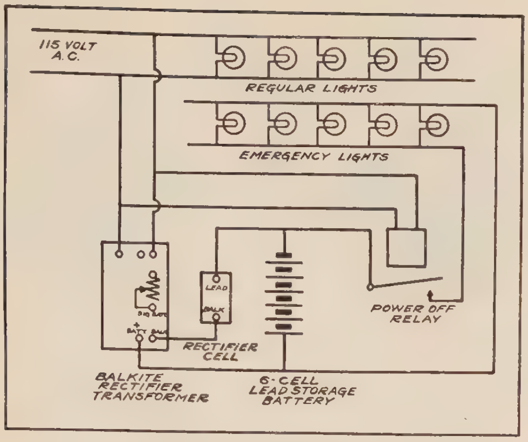
Even in non-industrial sections, the normal dust content of the air is high enough to warrant the installation of Midwest Air Filters to provide clean air for all rotary equipment, as well as for switch-rooms, bus-bar galleries, reactor coils, air blast transformers, storage battery rooms, etc.

The economic value of clean air, and the superior efficiency and operating economy of Midwest Air Filters have been proven by hundreds of installations in main and sub-stations of the electric light and power field.

Ask for Circular E-402.

MIDWEST AIR FILTERS
INCORPORATED

Bradford, Pa. *Offices in Principal Cities*



Balkite Trickle Charging
for
EMERGENCY LIGHTING

Hospital operating rooms must have light at all times because even a minute's darkness during a critical operation might prove fatal.

The simplest and most economical method of providing unfailing light is with the Balkite Trickle Charge System. In this system a Balkite Charger is connected to the regular power line and allowed to charge a storage battery continuously at a low rate. It thus automatically keeps the battery fully charged at all times.

A wiring diagram of a Balkite installation suitable for a small hospital is shown above. Immediately on the failure of the regular power supply the relay cuts in the emergency lights which draw their power from the storage battery. Many other situations where constant lighting is required can be handled in the same manner.

Balkite Trickle Charging is also adaptable to many other uses, wherever infallible power is required. A complete booklet fully describing the system and its operation is available on request. Write for it.

FANSTEEL
Balkite
Battery Chargers

FANSTEEL PRODUCTS COMPANY, INC.
NORTH CHICAGO, ILL.

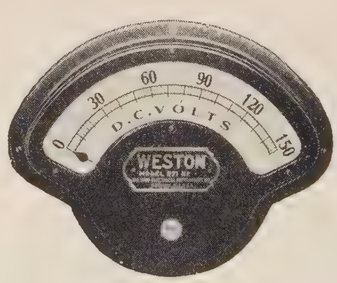
FANSTEEL PRODUCTS COMPANY, Inc., *North Chicago, Illinois*
Gentlemen: Please send me a copy of *Balkite Trickle Charging*

Name__________
Company__________
Address__________

Position__________

Adaptability of
WESTON
D. C. "Fan-Shaped" Instruments

THERE are four standard sizes of Weston Direct Current "fan-shaped instruments" provided for all panel requirements. ¶ The scales have the widest possible space, as the arc of the scale extends into the "fan-shaped" case. ¶ The scale lengths range from 2½ inches to 7³/₈ inches, are bold and legible and are the longest scales available for instruments of their size. ¶ The "fan-shaped" instruments have the same high degree of precision and long-life characteristic of the entire Weston line in four sizes suitable for every panel use. ¶ They have only a slightly noticeable projection from the front of the panel: they are unusually pleasing in appearance. Provided as D. C. Voltmeters, Millivoltmeters, Ammeters and Milliammeters. ¶ For further information request Bulletin 21.



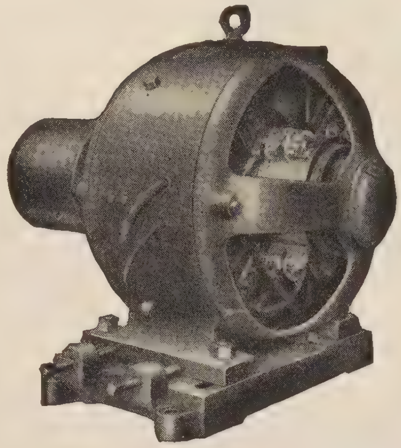
WESTON ELECTRICAL INSTRUMENT CORPORATION
48 Weston Avenue, Newark, N. J.

STANDARD THE WORLD OVER
WESTON
Pioneers since 1888

Pioneer Manufacturers of

INTERPOLE MOTORS

½ H. P. to 1000 H. P.



Type "S" Ball Bearing Motor with base and pulley

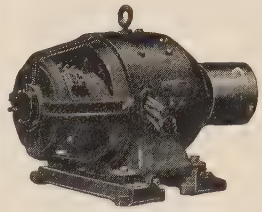
ELECTRO DYNAMIC COMPANY

Established 1880

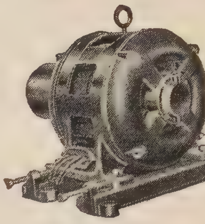
BAYONNE, N. J.

Sales Offices in Principal Cities

Star Ball Bearing Motors



For Hard Usage — A. C. and D. C.



Complete line of standard motors and generators, all sizes up to 75 h. p. and 50 kw. respectively.

Our Engineering Department at your service for all special applications

STAR ELECTRIC MOTOR CO.

NEWARK, NEW JERSEY

Trade "ESCO" Mark

ELECTRIC SPECIALTY CO.

Engineers and Manufacturers

DESIGN — DEVELOP — PRODUCE

Small Motors, Generators, Dynamotors, Motor Generators, Rotary Converters, Etc.

FOR SPECIAL PURPOSES

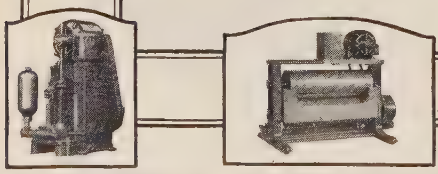
Send Us Your Problems

222 South Street STAMFORD, CONN., U.S.A.

Proof!

There's only one real test of quality in a motor — the *service* it gives. That MASTER MOTORS meet this test is evidenced by the fact that an ever increasing number of prominent manufacturers and jobbers are adopting them and that our customers continue to use and recommend them. Write for complete details.

THE MASTER ELECTRIC CO.
Linden and Master Aves.
Dayton, Ohio



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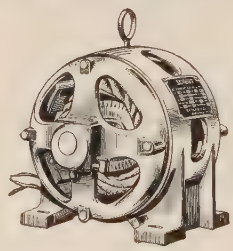
MASTER GUARANTEED MOTORS

⅛ TO 7½ H.P. Dayton THE MASTER ELECTRIC CO. Ohio Less than 40°

Sturtevant Electric Motors



—A. C. and D. C.; single and polyphase—built in sizes from small fractional to 250 horse-power—designed to operate under a constant full load where uninterrupted service is demanded.

B. F. STURTEVANT COMPANY

HYDE PARK, BOSTON, MASS.

DUNCAN

Watthour Meters

Model M2.

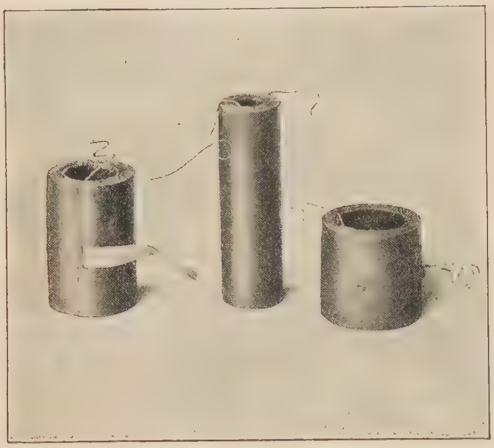
Accurate and Dependable

Write for bulletins

DUNCAN ELECTRIC MFG. CO.

Lafayette, Ind.

ACME WIRE PRODUCTS



Acme Coil Windings

Winding coils with an engineer's understanding of what they are expected to do does much to make them *uniformly* efficient in operation afterwards. Adding brains to blue prints is regular practice in the Acme plant . . . . because the same engineers who design special windings supervise *all* the windings going through. Acme Wire is uniform to a remarkably close tolerance. The winding is done on high-speed precision machines that maintain uniformity throughout long quantity runs.

Field Coils
—for automotive starting and lighting systems, and for farm lighting plants.

Ignition Coils
—wound to specification. Remarkably uniform. Tested under conditions far more severe than service requirements.

Meter Coils
—made with extreme care and accuracy. Resistance held within close limits. High grade coils for accurate instruments.

Transformer Coils
—for Radio "B" Power supply and for audio frequency amplification. Also bell ringing and toy transformers.

Write Our Nearest Office for Catalog 4A.

The Acme Wire Co., New Haven, Conn.

Branches at

New York, 52 Vanderbilt Ave. Chicago, 427 West Erie St.
Boston, 80 Federal St. Cleveland, Guardian Bldg.

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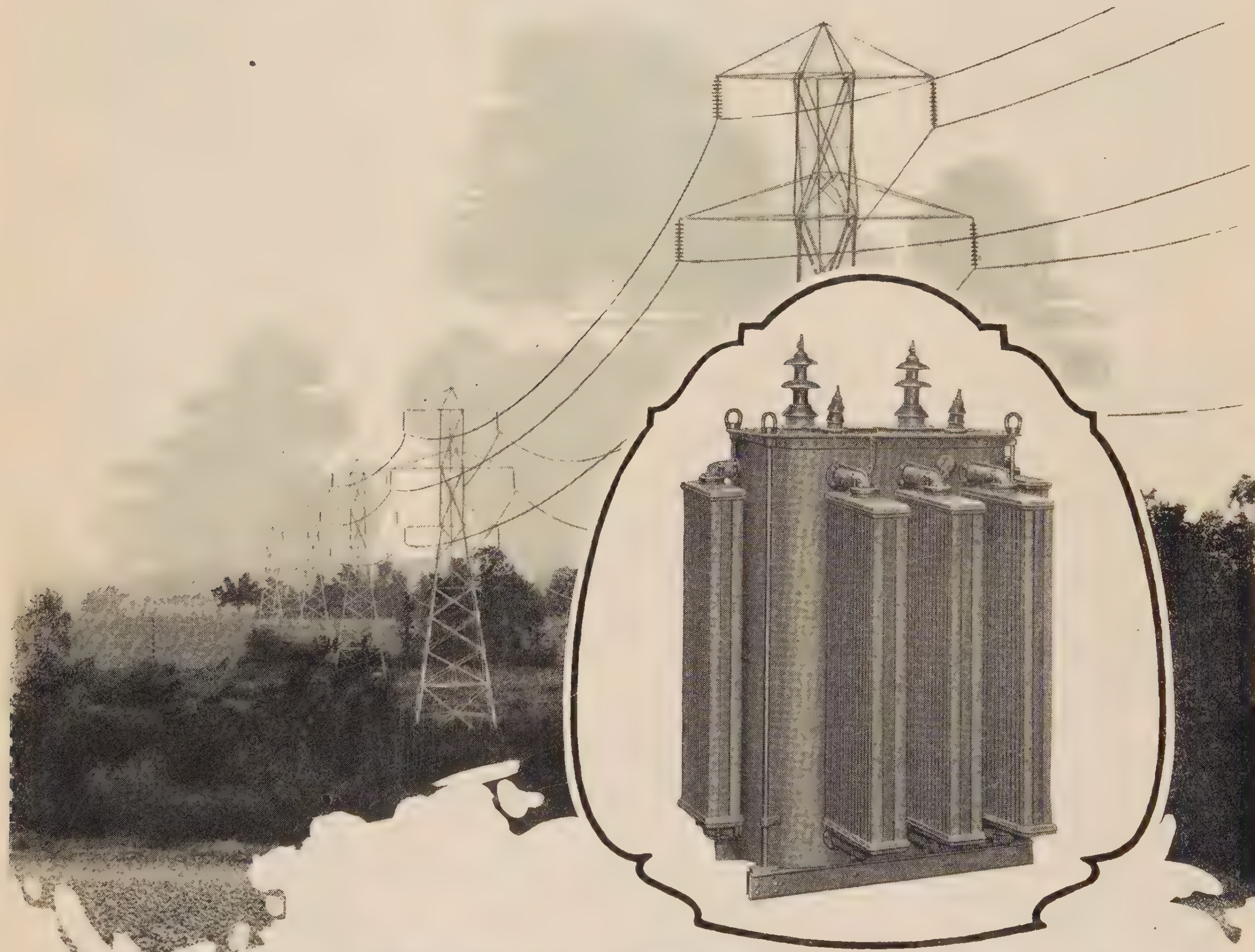
Classified Advertiser's Index for Buyers

Manufacturers and agents for machinery and supplies used in the electrical and allied industries.

Note: For reference to the Advertisements see the Alphabetical List of Advertisers on page 62.

By past performance Moloney transformers have earned their present nation-wide approval



MOLONEY

TRANSFORMERS

Moloney Electric Company, St. Louis, Mo.

Classified Advertiser's Index for Buyers—*Continued*

INSTRUMENTS, ELECTRICAL—*Continued*
Scientific, Laboratory, Testing
General Electric Co., Schenectady
Jewell Elec. Instrument Co., Chicago
Metropolitan Device Corp., Brooklyn, N. Y.
Roller-Smith Co., New York
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Weston Elec. Inst. Corp., Newark, N. J.
Telegraph
Western Electric Co., All Principal Cities
INSULATING MATERIALS
Board
West Va. Pulp & Paper Co., New York
Cloth
Acme Wire Co., New Haven, Conn.
Irvington Varnish & Ins. Co., Irvington, N.J.
Minerallac Electric Co., Chicago
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Composition
American Lava Corp., Chattanooga
Bakelite Corporation, New York
Belden Mfg. Co., Chicago
Westinghouse Elec. & Mfg Co., E. Pittsburgh
Compounds
Minerallac Electric Co., Chicago
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities
Fibre
National Vulcanized Fibre Co., Wilmington, Del.
West Va. Pulp & Paper Co., New York
Lava
American Lava Corp., Chattanooga, Tenn.
Mica
New England Mica Co., Waltham, Mass.
Paper
Acme Wire Co., New Haven, Conn.
Irvington Varnish & Ins. Co., Irvington, N.J.
Tullis, Russell & Co., Ltd., London, Eng.
Silk
Acme Wire Co., New Haven, Conn.
Irvington Varnish & Ins. Co., Irvington, N.J.
Tape
Belden Mfg. Co., Chicago
Minerallac Electric Co., Chicago
Okonite Co., The, Passaic, N. J.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Varnishes
Acme Wire Co., New Haven, Conn.
General Electric Co., Schenectady
Irvington Varnish & Ins. Co., Irvington, N. J.
Minerallac Electric Co., Chicago
INSULATORS, HIGH TENSION
Composition
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Glass
Hemingray Glass Co., Muncie, Ind.
Porcelain
General Electric Co., Schenectady
Lapp Insulator Co., Inc., ReRoy, N. Y.
Locke Insulator Corp., Baltimore
Ohio Brass Co., Mansfield, O.
Thomas & Sons Co., R., East Liverpool, O.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Post Type
Delta-Star Electric Co., Chicago
INSULATORS, TELEPHONE & TELEGRAPH
Hemingray Glass Co., Muncie, Ind.
Western Electric Co., All Principal Cities
LAMP GUARDS
Matthews Corp., W. N., St. Louis
Western Electric Co., All Principal Cities
LAVA
American Lava Corp., Chattanooga
LIGHTING FIXTURES
Cory & Son, Inc., Chas., New York
LIGHTNING ARRESTERS
Delta-Star Electric Co., Chicago
General Electric Co., Schenectady
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
LINEMEN'S PROTECTIVE DEVICES
Linemen Protector Co., Detroit, Mich.
LOCOMOTIVES, ELECTRIC
General Electric Co., Schenectady
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
METERS, ELECTRICAL
(SEE INSTRUMENTS, ELECTRICAL)
MICA
New England Mica Co., Waltham, Mass.
MOLDED INSULATION
Bakelite Corporation, New York
Belden Mfg. Co., Chicago
Burke Electric Co., Erie, Pa.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
MOLYBDENUM
Fansteel Products Co., Inc., North Chicago
MOTORS
(See GENERATORS AND MOTORS)
OHMMETERS
Cory & Son, Inc. Chas., New York
Jewell Elec. Instrument Co. Chicago
Roller-Smith Co., New York
Weston Elec. Instr. Corp., Newark, N. J.

OIL SEPARATORS & PURIFIERS
DeLaval Separator Co., The, New York
Sharples Specialty Co., The, Philadelphia
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
PANEL BOARDS
(See SWITCHBOARDS)
PATENT ATTORNEYS
(See PROFESSIONAL ENGINEERING DIRECTORY)
PLUGS
Delta-Star Electric Co., Chicago
General Electric Co., Schenectady
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
POLES, STEEL
American Bridge Co., Pittsburgh
Pacific Coast Steel Co., San Francisco
Western Electric Co., All Principal Cities
POLES—TIES, WOOD
Western Electric Co., All Principal Cities
POTHEADS
G & W Electric Specialty Co., Chicago
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities
PROTECTIVE DEVICES
Metropolitan Device Corp., Brooklyn, N. Y.
Western Electric Co., All Principal Cities
PULLERS, SLACK
Matthews Corp., W. N., St. Louis
PUMPS
Allis-Chalmers Mfg. Co., Milwaukee
PUMPS, SPIRAL
Cramp & Sons Ship & Engine Bldg. Co., The Wm., Philadelphia
RADIO LABORATORY APPARATUS
General Radio Co., Cambridge, Mass.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
RAILWAY SUPPLIES, ELECTRIC
General Electric Co., Schenectady
Ohio Brass Co., Mansfield, O.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
REACTORS
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Metropolitan Device Corp., Brooklyn, N. Y.
RECTIFIERS
Fansteel Products Co., Inc., North Chicago
General Electric Co., Schenectady
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
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Matthews Corp., W. N., St. Louis
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Burke Electric Co., Erie, Pa.
General Electric Co., Schenectady
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
RELAYS
Cory & Son, Inc., Chas., New York
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
RESISTOR UNITS
General Electric Co., Schenectady
Ward Leonard Electric Co., Mt. Vernon, N.Y.
RHEOSTATS
Biddle, James G., Philadelphia
General Electric Co., Schenectady
Sundh Electric Co., Newark, N. J.
Ward Leonard Electric Co., Mt. Vernon, N.Y.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
ROPE, WIRE
American Steel & Wire Co., Chicago
Roebling's Sons Co., John A., Trenton, N. J.
SEARCHLIGHTS
General Electric Co., Schenectady
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
SHEETS, ELECTRICAL
Trumbull Steel Co., The, Warren, O.
SOCKETS AND RECEPTACLES
General Electric Co., Schenectady
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
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Acme Wire Co., New Haven, Conn.
Belden Mfg. Co., Chicago
Dudlo Mfg. Co., Ft. Wayne, Ind.
General Electric Co., Schenectady
Sundh Electric Co., Newark, N. J.
Ward Leonard Electric Co., Mt.Vernon, N.Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
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General Electric Co., Schenectady
Rowan Controller Co., Baltimore, Md.
Sundh Electric Co., Newark, N. J.
Ward Leonard Electric Co., Mt.Vernon, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
STEEL, SHEET & STRIPS
Trumbull Steel Co., The, Warren, O.
STOKERS, MECHANICAL
Sturtevant Company, B. F., Boston
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SUB-STATIONS
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Westinghouse Elec. & Mfg. Co., E. Pittsburgh
SWITCHBOARDS
Allis-Chalmers Mfg. Co., Milwaukee
Condit Electrical Mfg. Corp., Boston
General Electric Co., Schenectady
Metropolitan Device Corp., Brooklyn, N. Y.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
SWITCHES *Automatic Time*
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Ferranti Meter & Transformer Mfg. Co., Ltd., Toronto, Ont.
General Electric Co., Schenectady
Minerallac Electric Co., Chicago
Sundh Electric Co., Newark, N. J.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Disconnecting
Burke Electric Co., Erie, Pa.
Condit Electrical Mfg. Co., Boston
Delta-Star Electric Co., Chicago
General Electric Co., Schenectady
K-P-F Electric Co., San Francisco
Matthews Corp., W. N., St. Louis
Thoner & Martens, Boston
Fuse
General Electric Co., Schenectady
Matthews Corp., W. N., St. Louis
Metropolitan Device Corp., Brooklyn, N. Y.
Thoner & Martens, Boston
Knife
Condit Electrical Mfg. Corp., Boston
General Electric Co., Schenectady
Matthews Corp., W. N., St. Louis
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Magnetic
Ward Leonard Electric Co., Mt.Vernon, N.Y.
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Condit Electrical Mfg. Co., Boston
General Electric Co., Schenectady
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
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Condit Electrical Mfg. Corp., Boston
General Electric Co., Schenectady
Rowan Controller Co., Baltimore
Sundh Electric Co., Newark, N. J.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
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Fansteel Products Co., Inc., North Chicago
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Western Electric Co., All Principal Cities
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Cory & Son, Inc., Chas., New York
Western Electric Co., All Principal Cities
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Olsen Testing Machine Co., Tinius, Philadelphia
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American Bridge Co., Pittsburgh
Pacific Coast Steel Co., San Francisco
Western Electric Co., All Principal Cities
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Allis-Chalmers Mfg. Co., Milwaukee
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Duncan Elec. Mfg. Co., Lafayette, Ind.
Ferranti, Ltd., London, Eng.
Ferranti Meter & Transformer Mfg. Co., Ltd., Toronto, Ont.
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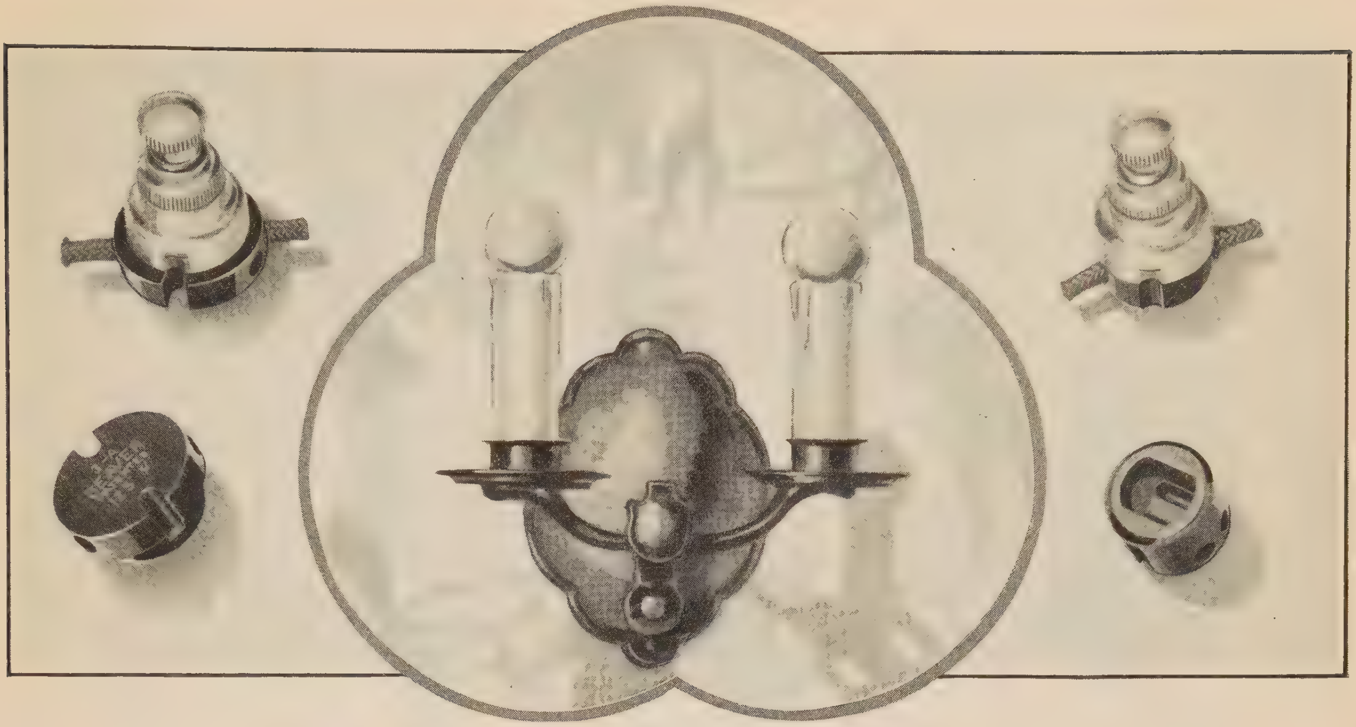
Kuhlman Electric Co., Bay City, Mich.
Moloney Electric Co., St. Louis
Pittsburgh Transformer Co., Pittsburgh
Wagner Electric Corp., St. Louis
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Factory
American Transformer Co., Newark, N. J.
Kuhlman Electric Co., Bay City, Mich.
Moloney Electric Co., St. Louis
Pittsburgh Transformer Co., Pittsburgh
Wagner Electric Corp., St. Louis
Western Electric Co., All Principal Cities
Furnace
Allis-Chalmers Mfg. Co., Milwaukee
American Transformer Co., Newark, N. J.
Moloney Electric Co., St. Louis
Pittsburgh Transformer Co., Pittsburgh
Metering
American Transformer Co., Newark, N. J.
Ferranti, Ltd., London, Eng.
Ferranti Meter & Transformer Mfg. Co., Ltd., Toronto, Ont.
Pittsburgh Transformer Co., Pittsburgh
Mill Type
Pittsburgh Transformer Co., Pittsburgh
Radio
American Transformer Co., Newark, N. J.
Street Lighting
Kuhlman Electric Co., Bay City, Mich.
Western Electric Co., All Principal Cities



Bakelite insulated Canopy Switches made by Beaver Machine and Tool Co., Newark, N. J.

Breakage losses eliminated — uniformity assured through molding of Bakelite

Porcelain was formerly used for the bases of these small canopy switches, but porcelain was brittle, could not be held to accurate dimensions and sometimes caused trouble because of surface roughness.

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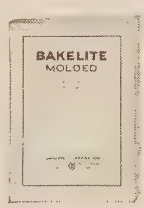
Bakelite is steadily replacing other materials for insulation parts of every size. Through its use assembly operations are being reduced, quality improved and frequently costs are lowered. Our engineers and research laboratories gladly cooperate with manufacturers in adapting Bakelite to their needs.



Our Booklet No. 3, "Bakelite Molded," illustrates and describes a variety of electrical applications. Your request would bring a copy by return mail.

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Cramp & Sons Ship & Engine Bldg. Co., The Wm., Philadelphia

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General Electric Co., Schenectady
Sturtevant Company, B. F., Boston
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

TURBINE SIGNAL SYSTEMS
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Westinghouse Elec. & Mfg. Co., E. Pittsburgh

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Bristol Company, The, Waterbury, Conn.
Cory & Son, Inc., Chas., New York

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Cramp & Sons Ship & Engine Bldg. Co., The Wm., Philadelphia

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Irvington Varnish & Ins. Co., Irvington, N. J.
Minerallac Electric Co., Chicago
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

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Ohio Brass Co., Mansfield, O.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

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Boston Ins. Wire & Cable Co., Boston
General Electric Co., Schenectady
Hazard Manufacturing Co., Wilkes-Barre, Pa.
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Roebling's Sons Co., John A., Trenton, N. J.
Simplex Wire & Cable Co., Boston
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

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Belden Mfg. Co., Chicago
General Electric Co., Schenectady

Automotive
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Atlantic Ins. Wire & Cable Co., Rome, N. Y.
Belden Mfg. Co., Chicago
Boston Ins. Wire & Cable Co., Boston
General Electric Co., Schenectady
Kerite Ins. Wire & Cable Co., New York
Roebling's Sons Co., John A., Trenton, N. J.
Simplex Wire & Cable Co., Boston
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

Bare Copper
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American Steel & Wire Co., Chicago
Anaconda Copper Mining Co., Chicago
Atlantic Ins. Wire & Cable Co., Rome, N. Y.
Belden Mfg. Co., Chicago
Copperweld Steel Co., Rankin, Pa.
Hazard Manufacturing Co., Wilkes-Barre, Pa.
Roebling's Sons Co., John A., Trenton, N. J.
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

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Copperweld Steel Co., Rankin, Pa.
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

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Belden Mfg. Co., Chicago
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General Electric Co., Schenectady
Hazard Manufacturing Co., Wilkes-Barre, Pa.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Simplex Wire & Cable Co., Boston
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

Fuse
General Electric Co., Schenectady
Roebling's Sons Co., John A., Trenton, N. J.
Western Electric Co., All Principal Cities

Lead Covered (Paper and Varnished cambric insulated)
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Anaconda Copper Mining Co., Chicago
Atlantic Ins. Wire & Cable Co., Rome, N. Y.
General Electric Co., Schenectady
Hazard Manufacturing Co., Wilkes-Barre, Pa.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Okonite-Callender Cable Co., The, Inc., Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Simplex Wire & Cable Co., Boston
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

Magnet
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Atlantic Ins. Wire & Cable Co., Rome, N. Y.
Belden Mfg. Co., Chicago
Dudlo Mfg. Corp., Fort Wayne, Ind.
General Electric Co., Schenectady
Roebling's Sons Co., John A., Trenton, N. J.
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

Rubber Insulated
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Atlantic Ins. Wire & Cable Co., Rome, N.Y.
Belden Mfg. Co., Chicago
Boston Ins. Wire & Cable Co., Boston
General Electric Co., Schenectady
Hazard Manufacturing Co., Wilkes-Barre, Pa.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Simplex Wire & Cable Co., Boston
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

Trolley
American Steel & Wire Co., Chicago
Anaconda Copper Mining Co., Chicago
Atlantic Ins. Wire & Cable Co., Rome, N. Y.
Copperweld Steel Co., Rankin, Pa.
Roebling's Sons Co., John A., Trenton, N. J.
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

Weatherproof
American Ins. Wire & Cable Co., Chicago
American Steel & Wire Co., Chicago
Anaconda Copper Mining Co., Chicago
Atlantic Ins. Wire & Cable Co., Rome, N. Y.
Copperweld Steel Co., Rankin, Pa.
General Electric Co., Schenectady
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Simplex Wire & Cable Co., Boston
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

ALPHABETICAL LIST OF ADVERTISERS

(For classified list of Advertisers see pages 56, 58 and 60.)

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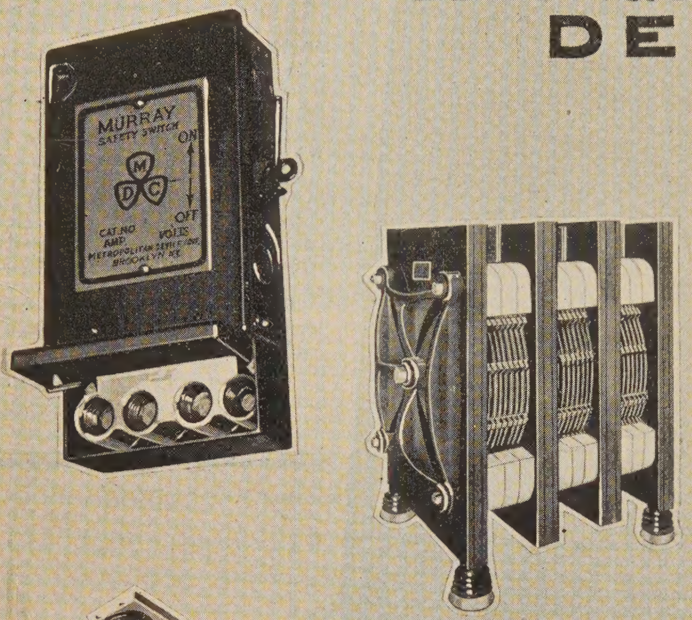
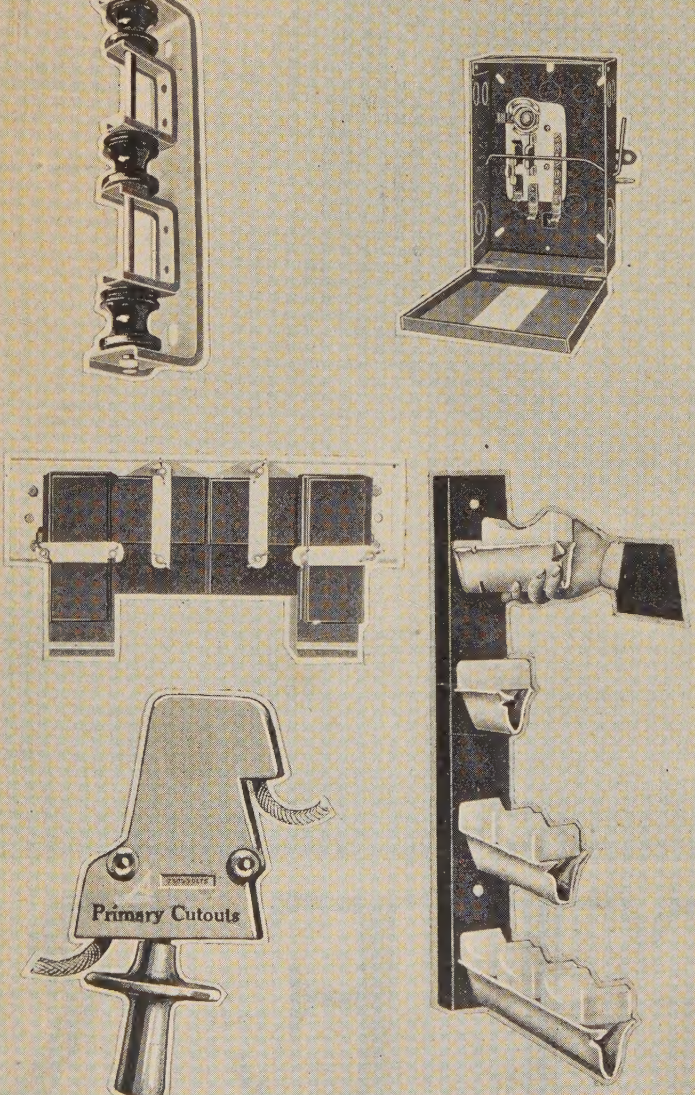
THE CUTTER COMPANY
Established 1885 · Philadelphia
1829 Hamilton Street

CUTTER

U-RE-LITE — I-T-E CIRCUIT BREAKERS

MURRAY
ELECTRICAL PROTECTIVE DEVICES





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1250 Atlantic Avenue
Brooklyn, New York

BELDEN MANUFACTURING COMPANY 239

Turns Per Square Inch

Table D

B. & S.	Beld-enamel	Single Cotton	Double Cotton	Single Silk	Double Silk	Cot-enamel	Silk-enamel
8	57	53	48	......	......	52	......
9	72	66	59	......	......	64	......
10	90	84	76	......	......	80	......
11	113	104	93	......	......	100	......
12	141	129	114	......	......	124	......
13	177	160	140	......	......	151	......
14	221	198	171	......	......	187	......
15	277	245	208	......	......	230	......
16	348	312	260	351	327	289	326
17	437	383	316	437	405	358	408
18	548	472	378	548	503	438	505
19	681	581	455	682	619	532	622
20	852	712	545	848	761	644	769
21	1065	868	650	1055	935	780	946
22	1340	1128	865	1315	1150	1008	1175
23	1665	1370	1030	1620	1400	1220	1440
24	2100	1665	1215	2010	1705	1475	1775
25	2630	2020	1420	2470	2070	1790	2180
26	3320	2445	1690	3005	2510	2155	2680
27	4145	2925	1945	3680	3010	2590	3275
28	5250	3500	2250	4600	3620	3100	4030
29	6510	4120	2560	5530	4270	3660	4865
30	8175	4900	2930	6810	5100	4320	5890
31	10200	5770	3330	8260	6010	5120	7170
32	12650	6700	3720	9870	6990	5960	8560
33	16200	7780	4140	11850	8160	7020	10400
34	19950	9010	4595	14250	9480	8060	12200
35	25000	10300	5070	16800	10870	9200	14500
36	31700	11750	5550	19850	12430	10550	17300
37	39600	13250	6045	23300	14100	12000	20400
38	49100	14900	6510	27300	15960	13400	23600
39	62600	16600	6935	31700	17850	15150	27850
40	77600	18400	7450	36700	19900	16750	32000

More Turns in Less Space

Beldenamel, Cotenamel and Silkenamel Wires are solving many difficult winding problems.

FOR motor rewinding, Cotenamel requires less space than double cotton-covered wire. Taking No. 18 wire, for example, 438 turns of Cotenamel can be wound in the same space as 378 turns of double cotton-covered wire. Many difficult rewinding jobs are made easy by using Cotenamel to replace double cotton-covered wire, and the insulating qualities of Cotenamel also are superior.

For high tension apparatus, Silkenamel is a great improvement over double silk-covered wire and you can wind more turns in less space.

MANUFACTURERS of electric motors, transformers, magnetic switches and other equipment provided with coil windings should investigate the advantages of magnet wire with Beldenamel insulation.

For many types of windings, Beldenamel wire is superior to textile covered wire. In addition to the space economy, indicated by the wire table, Beldenamel provides a higher factor of safety in insulation and an added protection against breakdown from moisture.

Send for interesting booklet on Beldenamel Wires

Specify Belden

USE THE COUPON

Belden Manufacturing Company
2316B So. Western Ave., Chicago

Please send us your booklet on Beldenamel Wire including winding data.

Name....................................

Address..................................

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